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FINAL TECHNICAL REPORT

MEASUREMENT OF INSULATION INTEGRITY OF I U E CAMERA
TUBE FACSIMILES BY PARTIAL DISCHARGES METHOD &
DIFFUSION OF GASES THROUGH VARIOUS SILICONE RUBBERS.

(NASA-CR-153293) MEASUREMENT OF INSULATION
INTEGRITY OF IUE CAMERA TUBE FACSIMILES BY
PARTIAL DISCHARGES METHOD AND DIFFUSION OF
GASES THROUGH VARIOUS SILICONE RUBBERS
Final Technical (District of Columbia

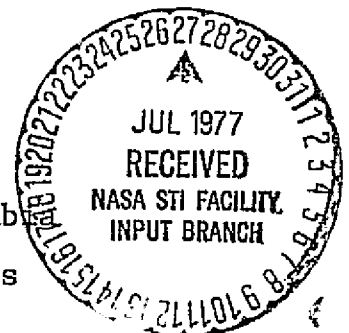
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Renate S. Bever, Principal Investigator

April 15, 1976 - April 15, 1977

NASA Grant # NGR 09-053-003, Supplement 2

University of the District of Columbia
Georgia Avenue/Harvard Street Campus
1100 Harvard Street, Northwest
Washington, D. C. 20009



FINAL TECHNICAL REPORT

MEASUREMENT OF INSULATION INTEGRITY C I U E CAMERA
TUBE FACSIMILES BY PARTIAL DISCHARGES METHOD &
DIFFUSION OF GASES THROUGH VARIOUS SILICONE RUBBERS.

(Formerly Study of Piezoelectric Transformers
for Space Use; Optical Degradation of Lenses
due to Material Condensation in Vacuum)

Renate S. Bever, Principal Investigator

April 15, 1976 - April 15, 1977

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1100 Harvard Street, Northwest
Washington, D. C. 20009

FOREWORD

As shown by the two communications attached, the carrying out of the originally proposed projects for this grant period, April 15, 1976 to April 15, 1977 was not judged to be propitious. Instead, the work performed consisted of the following two parts:

Part A: Measurement of Insulation Integrity of IUE Camera Tube facsimilies, by Partial Discharge Method.

The part played by the author in this study was as consultant and collaborator and interpreter of the data. This was done in conjunction with Goddard Space Flight Center, Greenbelt, Maryland, and with General Electric Space Systems Center, King of Prussia, Pennsylvania.

Part B: Diffusion of Gases through Silicone Rubbers. Consultation and measurements on Insulation problems on the Landsat C vidicon tubes.

UNITED STATES GOVERNMENT

Memorandum

TO : Renate S. Bever, Principal Investigator
NASA Grant NGR 09-053-003

DATE: July 16, 1976

FROM : John L. Westrom, Technical Officer
NASA Grant NGR 09-053-003

SUBJECT: New Direction and Change in Technical Subject Expressed
in the Current Grant

The present grant emphasizes: "Study of Piezoelectric Transformers for Space Use; Optical Degradation of Lenses Due to Material Condensation in Vacuum." This letter directs you to change the scope of your effort to the following:

1. Participate with Dr. Ben Seidenberg in the lense contamination study. It must be realized that the effort he is projecting cannot be fulfilled in the present time period of the grant. It can only be started due to the large amount of instrumentation to be fabricated and the number of test efforts to provide a clean and representative device fixture.
2. Study of partial discharge techniques on high voltage assemblies and components with the main emphasis on: (a) rejection criteria, and (b) noise levels in various high voltage capacitors.
3. Expand the permeation of gases through polymers to include empirical and mathematical methodology for determining the diffusion constant and solubility of space-grade encapsulants.
4. Provide expert consultive services on flight projects when directed in writing by the Technical Officer. This shall include efforts in partial discharge testing methods for IUE. In particular, the IUE contract with G. E., Valley Forge, using their Biddle partial discharge test equipment. It shall also include permeation, diffusion, and solubility measurements on silicone for Landsat-C RV/B.

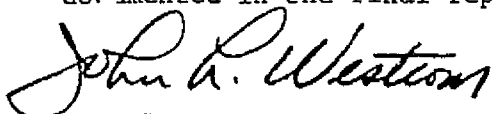


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Subject: New Direction and Change in Technical Subject Expressed
in the Current Grant

Because these efforts are more timely and of greater practical interest to the government, it is necessary to terminate all present activity on the piezoelectric transformer studies. All of the above tasks shall be documented in the final report for the year.



John L. Westrom

cc: A. Davidson, Code 401
L. Wilson, Code 430
G. Wiseman, Code 100
J. Mundy, Code 120
B. Seidenberg, Code 313
W. Forlifer, Code 710
F. Ford, Code 711
D. Harris, Code 711
E. Pasciutti, Code 711

711:JLW:11h:7-14-76



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771
October 28, 1976

REPLY TO
ATTN OF:

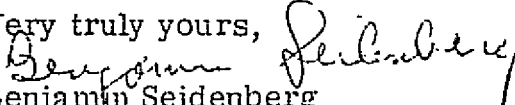
Mrs. Renate Beaver
Physics Department
D. C. Teachers College
Washington, D. C. 20009

Dear Mrs. Beaver:

One phase of Grant No. NGR-09053003 was to investigate the effect on optics as a function of contamination and contaminating levels. These studies were to be carried out using a Vac/Ion Titanium Sublimation System. During this period it was necessary to design and procure the necessary talent and monies. Both appeared to be lacking in that the design group has not been able to come up with a workable design that would not give rise to cross contamination of multiple specimens in vacuum. Also, during this time we finally found small Vac/Ion titanium sublimation systems that could accommodate one or two specimens. However, those units were in the hands of a contractor who needed money to make these spare parts into a workable unit. It should be noted that money to even accomplish this has not been available until recently.

At this point in time, the large chamber mentioned above is tied up with Landsat-C project assistance while the spare parts to make up a small system still are available but a clear definition as to time and money from the contractor has not been made available.

In the light of this additional and presently unresolved problem, the particular request for your aid was premature. This letter is intended to indicate a need to delay until some future time the test of the effect of contaminants on optics.

Very truly yours,

Benjamin Seidenberg
Materials Control & Review Office
Materials Control & Applications Branch
Code 313

ACKNOWLEDGEMENTS

Directions of Part A was by Mr. John L. Westrom of Goddard Space Flight Center, Greenbelt, Md., the data being taken by Mr. Jeffrey Benham of General Electric Co., King of Prussia, Pa.

Furthermore, the help rendered to this grant project by the following persons is hereby gratefully acknowledged: Mr. Art Davidson, Dr. John Park, Dr. Benjamin Seidenberg, Mr. Lou Wilson, Mr. Elijah Tankisley, Mr. Kenneth Young, all of Goddard Space Flight Center; Dr. Graham Thomas, Mr. Mike Sanford, of Science Research Council, Appleton Laboratory, Slough, U. K.; and Mr. Steve Peck and Mr. Joe Haydon, General Electric Company, King of Prussia, Pa; also Dr. J. D. Barnes of the National Bureau of Standards.

PART A.

ABSTRACT

Several dummy tubes imitating the IUE Camera System design were encapsulated with Solithane 2, Conathane EN-11, Green and Black Hysols and SMRD 432. Various flaws were purposefully placed in some of these. Partial Discharge testing in vacuum under Direct Voltage conditions was carried on once a week for 12 weeks, 15 kv d.c. being applied during normal working hours for 40 hours duration per week.

None of the units showed much damage during this time judging by the P.D. energy histograms. Two of them, especially one with severe delaminations had enough change in the histogram nevertheless, to warrant further testing for 10 more weeks. The Solithane 2, Conathane EN-11 proved to be good insulating materials; the Green and Black Hysols were poor insulators, and SMRD 432 was electrically noisier than unfilled materials.

In order to accelerate aging of the insulation, at least one dummy tube should be subjected to a.c. voltage at a.c. corona inception for various time intervals, and the progressive changes in partial discharge behavior be tested alternately by a.c. and d.c. methods.

PART B:

ABSTRACT.

A more complete mathematical presentation is given on diffusion and permeation than previously. Measurements of diffusion constants for various silicone rubbers are carried out by the Time-Lag method and compared to other determinations in the literature. Calculations of the time required for diffusion through a thick wall are demonstrated in the long time approximation and for dimensions pertaining to void and wall sizes of a delamination problem in the Landsat-C vidicon tubes. An actual delaminated Landsat-C tube and some facsimiles are immersed in vacuum for long periods and tested for catastrophic breakdown due to diffusion of gas, by application of high voltage.

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PART B.

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Diffusion through Thick Walls

- a) Improved Mathematical Theory for Diffusion and Permeation
- b) A Sample Calculation
- c) Measurement of Diffusion Coefficients on Silicone Rubbers
- d) Insulation Problem on Landsat-C Vidicon Tubes

PART A:

MEASUREMENT OF INSULATION INTEGRITY
OF I U E CAMERA TUBE FACSIMILES
BY PARTIAL DISCHARGE METHOD

I. PURPOSE

To measure five (5) encapsulated systems for adequate and reliable performance in the IUE Camera System. Each candidate system must fulfill these requirements

- 1) Buffer and protect each camera tube from mechanical damaging vibration. . . . the launch environment.
- 2) Withstand potential voltage stress of up to -14 KVDC in vacuum (less than 10^{-5} torr) for a three to five year mission life.

II. PRESENT CAMERA SYSTEM

A generalized view of the present camera system is shown in Figure 1. It includes a UV Converter operated at a potential (remotely programmable) from -4 KVDC to -6 KVDC. However, this potential is with respect to the SEC Vidicon tube anode which also is remotely programmed from -2 KVDC to -8 KVDC with respect to spacecraft and instrument ground. Thus the total worst case voltage from the UV Converter to ground can vary from -6 KVDC to -14 KVDC.

III. THE MAJOR PROBLEM

The present encapsulant (Solithane C-113, Formulation #6) is vacuum-encapsulated around the camera tube held in a fixed configuration by a mold, the inside contour of the mold forming the irregular shape of the encapsulant per Fig. 1. This contour and the flexibility of the encapsulant (45-55 shore A) provide the mechanical buffering for the tube. However, the Solithane-type polyurethane has a tendency to develop cracks under applied stress. This latent defect raises grave concern for operation at high voltage potentials in vacuum or during the system transition to vacuum (less than 10^{-5} torr).

IV. SAMPLE ENCAPSULATION SYSTEMS FOR TEST

It is thus proposed that several encapsulation systems be tested to determine the relative merit of each. The test shall measure each energized system's noise level to a optimum sensitivity of one picocoulomb. It will provide an acceptance criteria for selecting a reliable encapsulation system. Each sample will consist of an aluminum inner electrode manufactured to the same contour as a tube; the proposed encapsulant that is vacuum encapsulated to the same specifications as the IUE

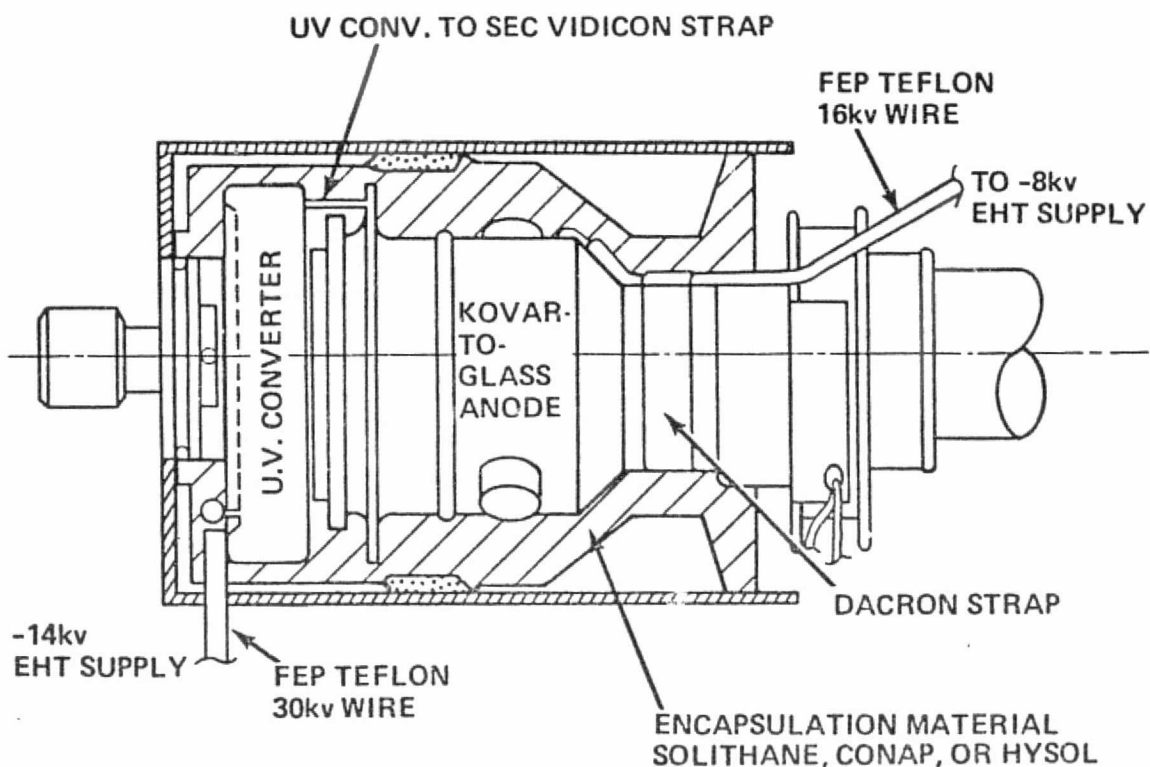


Figure 1. View of Encapsulated Camera System

Cameras; the high voltage cable is captured in a similar fashion as the camera's within the encapsulant; and a cylindrical aluminum shell shall surround the system as a ground plane. This sample configuration is shown in Figure 2a.

V. FIVE SAMPLE UNITS

Figure 2a shows a typical configuration to be used for testing. Each of five samples shall be manufactured at GSFC. Each encapsulation system shall be one of the following:

- 1) Solithane, formulation # 2 with Woolsey Metalast 920 primer.
- 2) Same encapsulant as 1) with an appropriately located continuous cut (electrode-through-to-outer-surface).

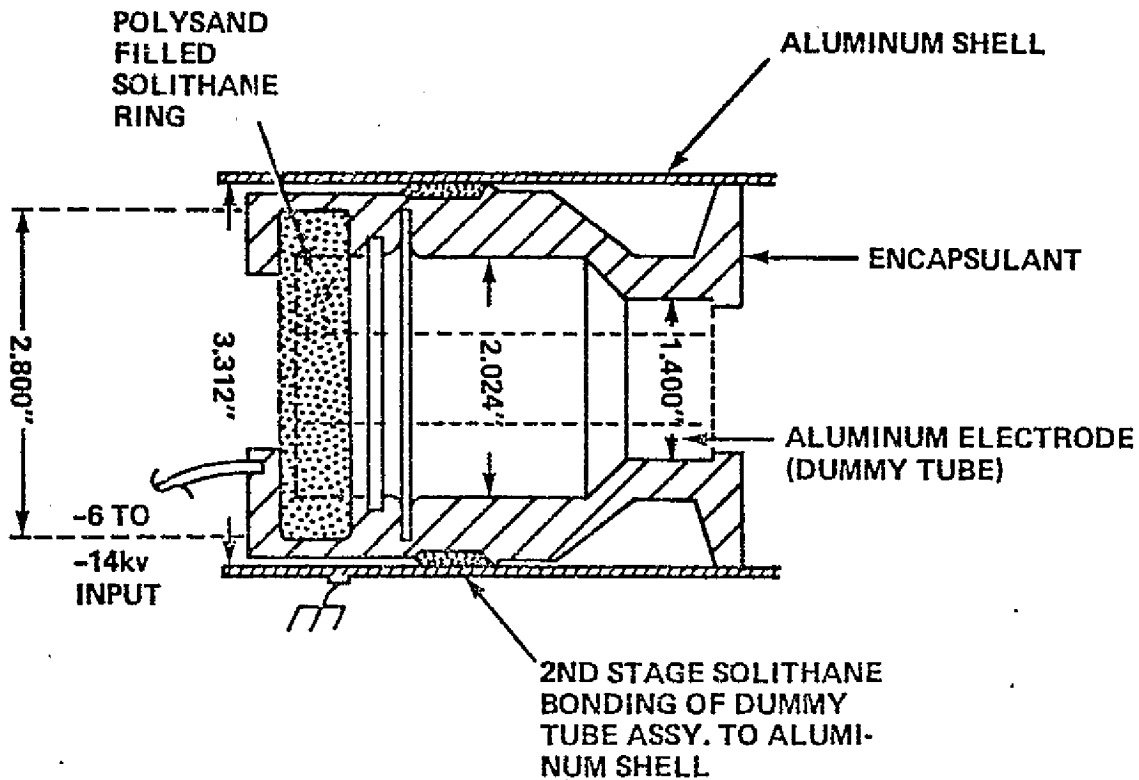


Figure 2a. Typical Sample Configuration

- 3) Same encapsulant as 1) with a small piece of teflon inserted on the electrode to duplicate lack of adhesion of encapsulant-to-electrode surface.
- 4) Same encapsulant as 1) with thermally induced stress cracks.
- 5) Conap EN-11 polyurethane with primer PR 420. This encapsulated system will undergo the same thermal stress as sample 4).

Each sample specimen shall be prepared using the cleaning and process control specified by MARCONI's M.S.D.S. IUE requirements:

- 1) IUE-SH-G30328, Cleaning of SEC Vidicon Tubes.
- 2) IUE-SH-G30323, Encapsulation procedure for camera tube.
- 3) IUE-SH-G30330, Potting of camera tube into housing.

As well as any later detail input from SRC/MSDS concerning any of the above methodology.

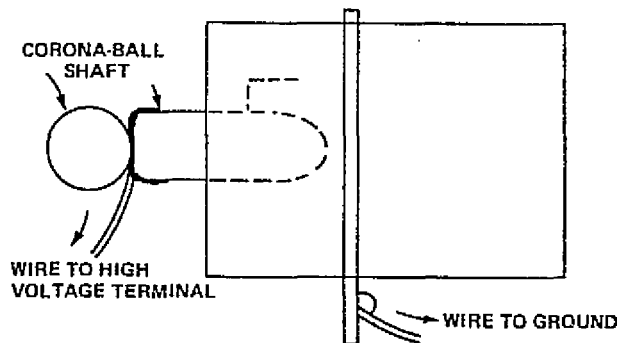


Figure 2b. External Appearance of Sample

VI. THE D. C. CORONA DETECTION EQUIPMENT

It is requested that the Biddle Partial Discharge Detection System be used for this testing program. This unit has the capability of energizing a high voltage insulation system and identifying latent material defects with a sensitivity of one picocoulomb (for small system capacitance). The unit consists of a dc corona-free (with separation filter) power supply which can be varied from -1 KVDC to -40 KVDC, a low impedance shunt filter, and a calibrated, resonant-pulse detection system. Any charge pulse occurring above this sensitivity within the test sample is counted as an event, and its pulse height is measured to determine charge magnitude. A pulse height analyzer with memory and storage display provides an accurate histogram of the number of events and their charge amplitude in time, (NUCLEAR DATA ND 100).

This sensitive equipment will monitor an insulation sample stress of several voltages in vacuum (less than 10^{-5} torr), so that qualitative measurements of encapsulant integrity are recorded over time.

The equipment shall be installed in a noise-free environment (preferably in a shielded screen-room).

VII. ADDITIONAL EQUIPMENT FOR DC CORONA TESTING IN VACUUM

A separate -20 KVDC power supply shall be used for energizing each insulation sample in vacuum between measurement intervals when the

Biddle system is used. Therefore the Biddle system will not have to be dedicated exclusively to this testing program, but only when measurements are scheduled. During the remaining time, a strip chart recorder should be inserted on the ground side of the line. Its sensitivity should be 0-100 uA full scale with an accuracy of $\pm 3\%$. The recording device should have a chart speed of 4 inches per hour. A high voltage meter (approx. 100 Mohm to 1000 Mohm input impedance) is required to monitor and record the voltage levels. It requires a full scale reading of at least 18 KVDC with an accuracy of $\pm 3\%$. Figure 4 shows the required test set-up.

VIII. AC CORONA DETECTION EQUIPMENT

The same Biddle corona detection system is used except that a separate high voltage AC power supply is required. The corona inception and extinction voltage is displayed on a 5" CRO display tube which is a part of the Biddle Partial Discharge Detector. The Lissajous pattern provides periodic display of any corona condition. The amplitude of the noise spikes are a direct measure of the charge in picocoulomb. This test will not be instrumented into the vacuum chamber. It would cause additional difficulties in limiting current and power because of the AC waveform. This test set up is shown in Figure 5.

IX. THE VACUUM SYSTEM

The vacuum system shall consist of the following minimum requirements:

- 1) 18" diameter Pyrex bell jar
- 2) Mechanical roughing pump
- 3) Diffusion pump
- 4) Miscellaneous cold trap and valves as described in the discussion below
- 5) 5 each high voltage feedthroughs rated at 20 KVDC. Similar to Veeco Type HVF, P/N 9800-741

This system is required to provide a vacuum capability of at least 10^{-5} torr. The system must be designed to prevent backstreaming of oil

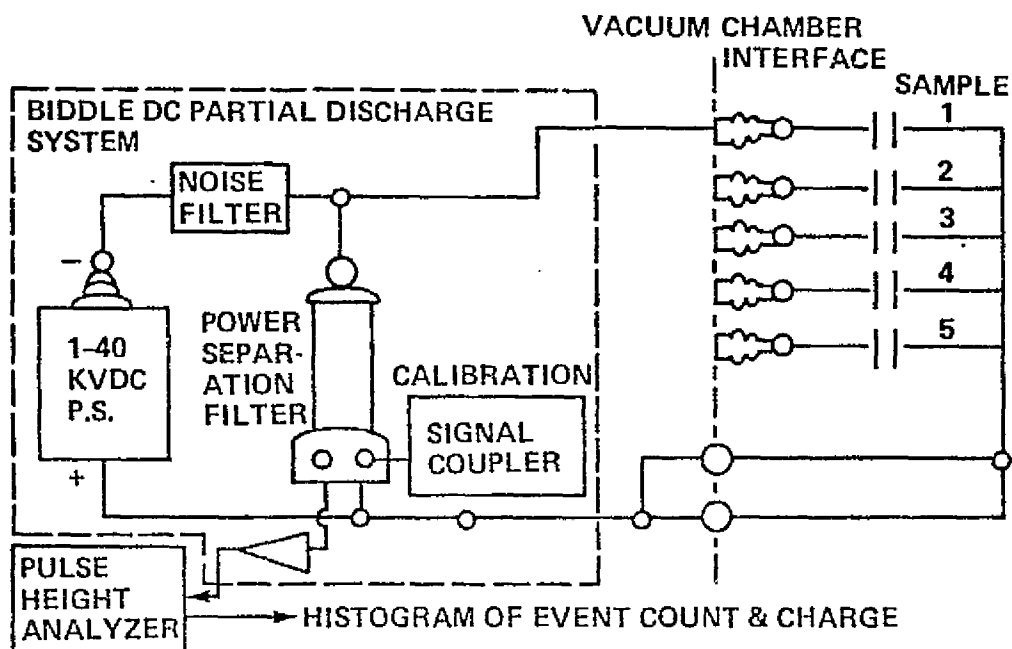


Figure 3. Test Set-up for Measuring DC Partial Discharge

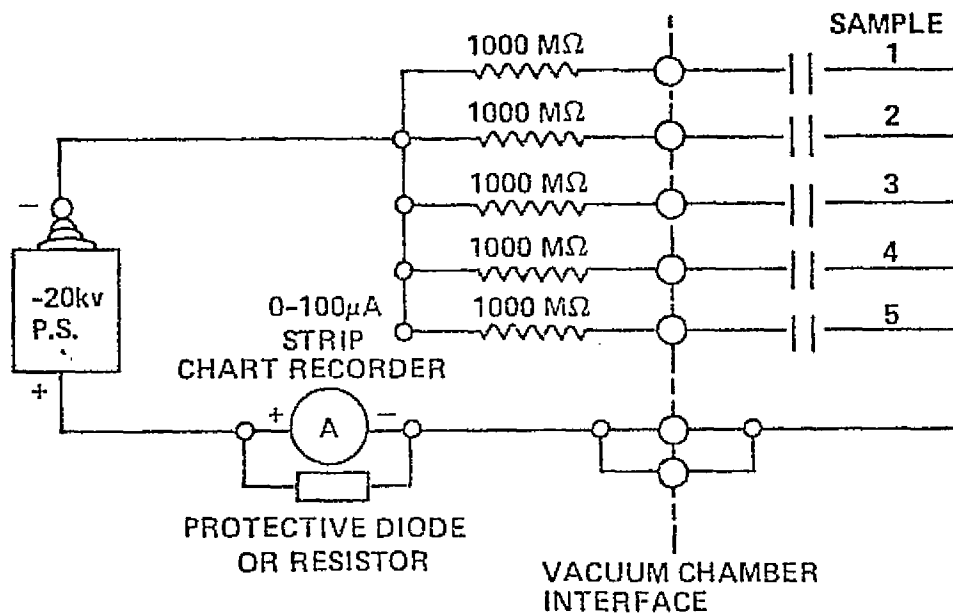


Figure 4. System Hook-up when Biddle System Not Used

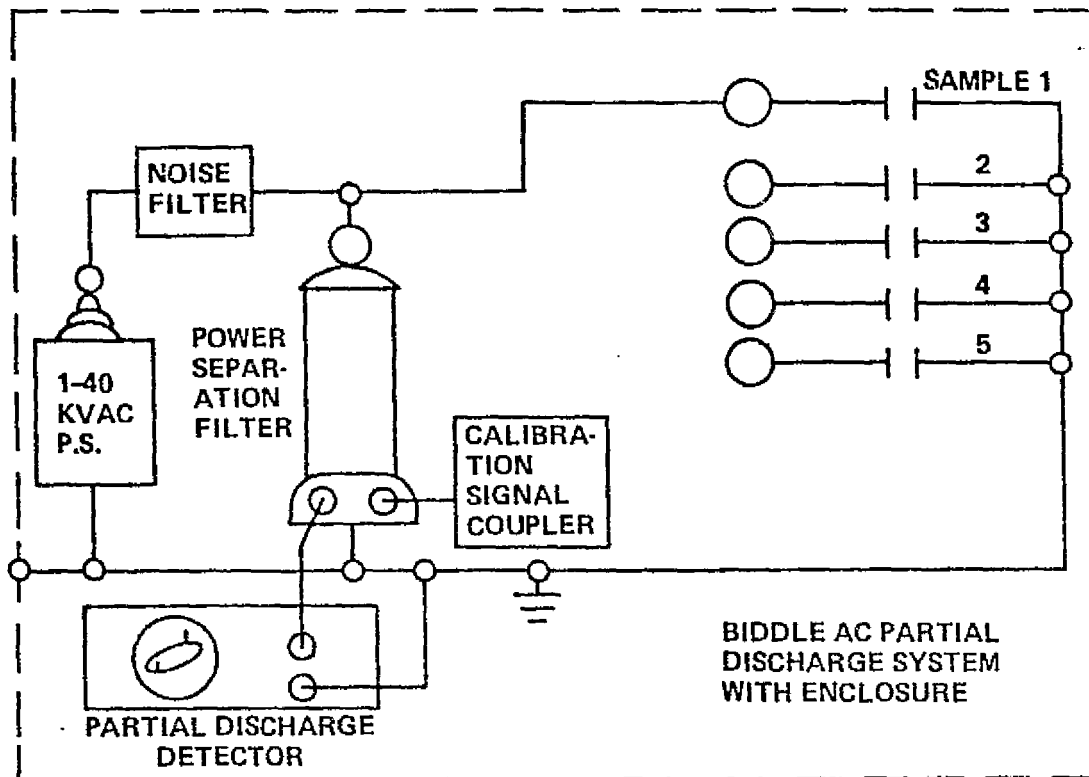


Figure 5. Test Set-up for Measuring AC Partial Discharge

vapors into the bell jar. It is expected that the test will be terminated during weekends so that the vacuum system will be turned off. However, vacuum is to be maintained in the bell jar so that the testing program can reconvene with minimal interruption on the next workday. Because of the high voltages present and the sensitive measurements being performed, it is imperative that no contaminants, especially oil vapors, can enter the bell jar during this time. Therefore one of the following methods should be considered for preventing this backstreaming:

- 1) keep LN_2 continuously on the cold trap between the diffusion pump and the high vacuum portion of the system.
- 2) close a leak tight valve between the diffusion pump and the high vacuum portion of the system.

In performing this kind of measurement at GSFC, it has been apparent that contamination will occur when the vacuum system is turned off for weekends unless the above or similar precautions are taken. Of course, once contaminated, the oil vapor will ionize and give false count measurements at these potentials.

X. TRANSPORTATION REQUIREMENTS FOR SAMPLES

The contractor shall use reasonable and proper handling precautions both in shipment and handling during the testing program. He shall not be held liable for replacement of any unit. However, if it is shown that improper handling may have compromised a sample, the test data being invalidated, he shall be held responsible for redoing the testing and recording the data on a fresh sample provided by GSFC. This will be done at no additional cost to the government.

XI. THE TEST PLAN

At the contractor's facility each test sample shall be measured using their Biddle DC and AC partial discharge detection system and pulse height analyzer. This testing is to be done at room ambient conditions for initial characterization of all samples before any vibration or vacuum testing.

- 1.0 Measure and record the DC corona susceptibility for each system with the Biddle DC partial discharge detection unit and the pulse height analyzer inside the Biddle test enclosure.
- 1.1 Measure the test system's sensitivity with no sample installed. Record all events and their charge magnitude for three successive 200 sec. intervals. Use the maximum expected voltage of -15 KVDC.
- 1.2 Measure each test sample, para V. 1) through 5) at the following voltages, or until obvious high energy partial discharge is apparent at or below any test voltage:
 - a) -6 KVDC
 - b) -8 KVDC
 - c) -13 KVDC
 - d) -15 KVDC

Record all event counts and their magnitude for three successive ~~200~~ sec. intervals at each voltage level. If high energy discharges occur before all voltage levels are measured, record these events at that inception voltage. This may be at or less than the level specified. Do not continue measurements above this voltage level on this sample.

- 1.3 Recheck the system sensitivity by repeating step 1.1.
- 2.0 Measure each test sample at room ambient conditions within the Biddle test enclosure and using the AC partial discharge detection system.
- 2.1 Measure the test system sensitivity with on sample installed. Use maximum expected voltage of 10.6 KVAC, (rms).
- 2.2 Measure each test sample, para. V, 1) through 5) at the following voltages, or until obvious high energy partial discharges are apparent at or below any test voltage:
 - a) 4.25 KVAC (rms)
 - b) 5.66 KVAC (rms)
 - c) 9.20 KVAC (rms)
 - d) 10.60 KVAC (rms)

Observe and record any inception occurrences at each voltage level on the lissajous pattern. Record the maximum charge magnitude of each occurrence. Also record the ac current if it is measurable on the Biddle power supply meter. If high energy discharges occur before all voltage levels are measured, record these events at that inception voltage. This may be at or less than the level specified. Do not continue measurements above this voltage on this sample.

- 3.0 The contractor shall return all samples with their accompanying documentation to GSFC following the procedure outlined in para. X, transportation requirements.
- 3.1 At GSFC and at government expense a vibration test shall be performed on all samples to the levels required by the latest IUE 501 specification. The contractor must allow at least four (4) working days after delivery of these test samples before they will be

released by GSFC for return by him to his facilities. All packing and containers shall be provided by GSFC.

3.2 The contractor shall return all samples with their accompanying documentation to his facility following the procedure outlined in para. X, transportation requirements.

4.0 Repeat steps 1.0 and 2.0 within the Biddle test enclosure.

5.0 Instrument the test samples into the vacuum system as shown on Figure 3, and discussed in para. IX.

5.1 Repeat step 1.0 within the vacuum system at room ambient conditions.

5.2 Evacuate the vacuum chamber to less than 10^{-5} torr; allow the samples to soak at this pressure for at least one (1) hour.

5.3 Repeat step 1.

5.4 Instrument the dc test set-up shown in Fig. 4. All samples are energized through the high voltage interfaces with the auxiliary -20 KVDC supply. The voltage on the supply shall be set to -15 KVDC at the high voltage connector/vacuum interface. The current is limited in each sample to 15 μ ADC. Upon request by the contractor, GSFC is prepared to furnish the contractor:

- a) -20 KVDC power supply
- b) all 20 Kv high voltage resistors
- c) five each 20 KV high voltage feedthroughs

Note: Current should be continuously recorded on the strip chart recorder whenever the -20 KVDC supply is energizing samples.

6.0 Upon completion of a work day, testing is to be terminated as follows:

- a) turn off all high voltages
- b) all valving of LN_2 for cold trap is to be accomplished to insure that no backstreaming shall occur during shutdown. The high vacuum portion of the system being now isolated from both mechanical and diffusion pumps.
- c) the vacuum system turned off.
- d) all test equipment turned off.

7.0 To begin a work day, testing turn-on shall be accomplished in the following sequence:

- a) turn on all test equipment (except no high voltage is to be turned on yet).
- b) turn on the vacuum system bringing the pressure below 10^{-5} torr.
- c) record the pressure that the system had leaked to before pump down.
- d) After approximately 10 minute soak at 10^{-5} torr, turn on high voltage or continue proposed test.

XII. SCHEDULE

- 1.0 Kickoff Conference, upon award. A kickoff conference shall be held at GSFC with two representatives of the contractor for the purpose of clarifying and understanding the scope of the contract.
- 1.1 At this time all test samples shall be delivered to the contractor per para. X.
- 1.2 Instrument and measure each sample at the contractor's facility using the Biddle Partial Discharge detection system both AC and DC as described in para. XI, step 1 and step 2.
- 1.3 Samples are to be returned to GSFC for vibration per para. XI, step 3.
- 2.0 All test samples shall be delivered to the contractor per para. X.
- 3.1 Instrument and measure each sample at the contractor's facility using the Biddle Partial Discharge Detection System both AC and DC as described in para. XI, step 1 and step 2.
- 3.2 Instrument each sample into the vacuum system as described in XI, step 5.
- 3.3 Measure each sample with the Biddle DC System as described in XI, step 5. 1.
- 3.4 Prepare and checkout vacuum system including instrumenting the high voltage feedthroughs.

- 4.0 Begin vacuum testing, record starting time.
- 4.1 Turn on vacuum system and initiate test program as described in para. XI, step 7.
- 4.2 Measure and record test samples in vacuum as described in para. XI, step 1; in addition, note step 5.2, in para. XI.
- 4.3 Initiate para. XI, step 5.4. Record voltages of sample and the current reading on the strip chart recorder. Record starting time.
- 4.4 Terminate each day per para. XI, step 6, recording termination time.
- 4.5 Begin testing each day per para. XI, step 7, recording starting time.
- 4.6 On last day of work week again measure the samples with the Biddle DC System as described above in para. XI, step 1.

Repeat all of steps required for week 4 above in weeks 5, 6, and 7. Should any difficulties occur during the testing variations must be mutually agreed to by the contractor and the T.O. All such variations must be in writing and signed off by both parties.

- 8.0 This week is set aside to formalize all documentation compiled during the testing. There is no requirement to type any listing of data. Clear and legible hand written listings are adequate. However, all headings and discussion material shall be typed. A total of twelve copies plus the reproducible original is required as a deliverable end item along with the tested samples.
- 8.1 A final meeting shall be held at GSFC on the last day of this week in which the documentation will be discussed, the samples and test results delivered. Two contractor representatives should be present, one of them being the person performing the measurements on the Biddle Equipment.

XIII. REJECTION CRITERIA

The purpose of this testing is to arrive at a decision based upon measured test data about the ability of several proposed encapsulation

methods to function successfully for the IUE mission duration and at rated performance levels. The rejection criteria must be a definite, continual increase of charge magnitude over time on any test sample. There should be no disagreement that a continual increase of charge build up over time must terminate with insulation breakdown.

Since this testing has been used as a research tool in the past, but not with five independent samples measured at the same time, the resulting data may allow for more significant interpretation. But as a minimum significant criteria, definite and continual increase in charge magnitude with time, will identify highly probable insulation system failure.

XIV. NEW TASKS

The following new tasks are required to be performed by the General Electric Company on Contract NAS5-23412 Modification No. 32.

1. Manufacture a test stand to house 7 each dummy IUE camera tubes as described on Engineering Sketch No. 1, enclosed. This stand will mount within the 18" DIA Vacuum Bell Jar for separating each dummy tube element.
2. Purchase 3 each 20 KV high voltage flanges for corona-free operation in the vacuum system. The flanges are V4-140D and can be purchased from Material Research Corporation.
3. Modify four available vacuum flanges and the newly purchased three vacuum flanges to be corona-free at 20 KVDC using schedule 1.

The modification shall consist of removing the presently installed cable on the vacuum side. In its place install Dielectric Science No. 2024, 60 KVDC silicone cable. Each unit shall be cleaned with isopropyl alcohol, and detergent with water as required. Each unit is then installed into the vacuum chamber's penetration ring and tested per Schedule 1 using the Biddle DC Partial Discharge System.

4. The contractor shall instrument and test eight two foot sections of high voltage cable provided by GSFC. The testing shall be done on two separate occasions with four samples for each test. The Biddle Partial Discharge System shall be used per Schedule 2. Cable Type A is W. L. Gore cable rated at 30 KVDC; Cable Type

B is W. L. Gore Cable rated at 16 KVDC. Both have teflon FEP 100 type insulation. He shall record data on all measurements taken.

5. The contractor shall instrument and test two high voltage resistor assemblies provided by GSFC. All end terminations and cabling shall be provided by the contractor. Shelf area shall be available on the test stand (Task #1) to support each resistor assembly and its associated instrumentation. Each assembly shall be rated at 25 KV and will dissipate no more than 250 MW each. Their function shall be to provide energizing voltage for the UV converter and SEC vidicon tubes. They are each to be tested per Schedule 1 using the Biddle System. He shall record data on all measurements taken.
6. The contractor shall instrument and test three each UV converters provided by GSFC per Schedule 3 using the Biddle System. All will be tested on the same day. He shall record data on all measurements taken.
7. The contractor shall instrument and test three each sec vidicon tubes provided by GSFC per Schedule 4 using the Biddle System. All will be tested on the same day. He shall record data on all measurements taken.
8. The contractor shall test and instrument three bonded pairs of UV converters/SEC vidicon tubes furnished by GSFC and tested per Schedule 5. Each will be tested on the Biddle System using the same resistor divider. He shall record data on all measurements taken.
9. The contractor shall test and instrument two encapsulated camera tube assemblies furnished by GSFC with their associated resistor divider assembly per Schedule 5. He shall record data on all measurements taken.
10. The contractor shall install and instrument the two encapsulated camera tube assemblies into the vacuum system. The test stand shall be modified to include these two units with full instrumentation and at least four dummy tubes which will remain uninstrumented during the vacuum testing. The vacuum testing shall last for six weeks with 24 hour, 7 days per week operation of the cold trap on the vacuum system. The Biddle System shall be used to

test the two units once per week per schedule 6. He shall record data on all measurements taken.

11. The contractor shall instrument and test six additional samples using the Biddle System at STP. Testing shall occur on three separate days with each test at two distinct DC voltages with 200 sec exposures each. He shall record data on all measurements taken.

12. The contractor shall prepare a testing procedure discussing:

- 1) Cleaning Procedure
- 2) Instrumentation
- 3) Test Procedure

For measuring with the Biddle System for repeatable results. He shall also document the data nomenclature and symbols from the pulse height analyzer to obviate ambiguity.

13. The contractor shall provide in systematic and legible form all data measurements taken under tasks: 4 through 11. This documentation may include all data recorded previously under the original contract for convenience.

14. The contractor shall be required to travel to GSFC on two separate occasions. Up to two contractors shall come on each trip.

The additional work required on this contract shall extend the length of the contract until February 14, 1977.

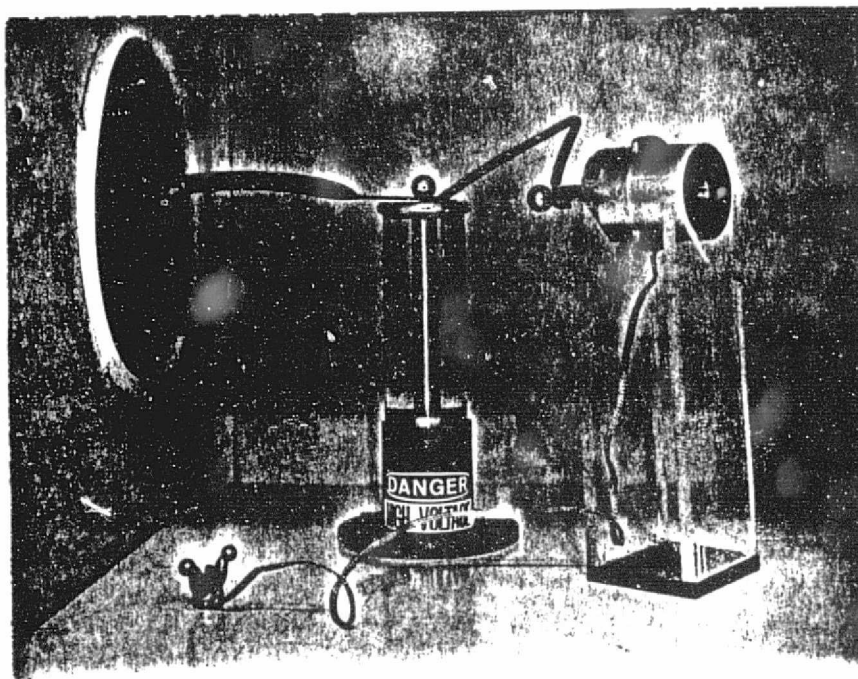
For the purpose of final clarification, a supplemental meeting shall be held at G. E., Valley Forge, PA for the purpose of clarifying final testing, procedures, demonstration of the Biddle System, and schedule requirements, as well as an inspection of the intended vacuum facility/ Biddle System. GSFC will send approximately eight people to the meeting.

XV. MORE NEW TASKS

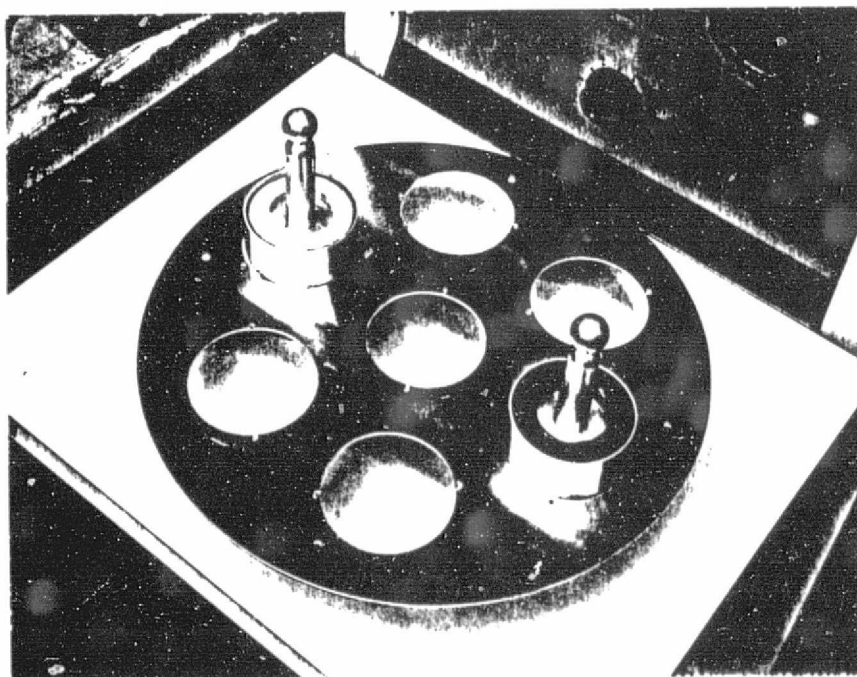
-- Friday -- Dec. 17th

- 1) Calibrate the Biddle System
- 2) Instrument the following units into the vacuum system
 - a) SN04

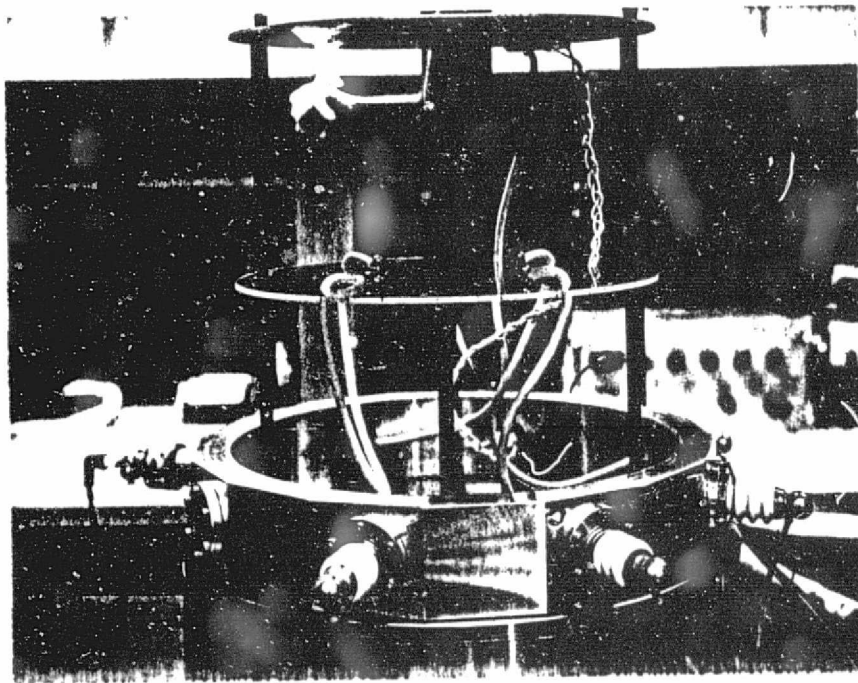
- b) SN07 (control sample)
- c) SN09
- d) SN05
- 3) Measure each dummy tube at the following voltages for 200 sec. each
 - a) 12 kV
 - b) 15 kV
 - c) 18 kV
 - d) 20 kV
- Monday -- Dec. 20th
 - 1) Pump down to 10^{-5} torr in morning
 - 2) Calibrate Biddle System in afternoon
 - 3) Repeat step 3 above for Dec. 17th in afternoon
 - 4) Maintain vacuum until closing time/turn off/restart the next day.
- Tuesday -- Dec. 21st
 - 1) Pump down to 10^{-5} torr in morning
 - 2) Calibrate Biddle System in afternoon
 - 3) Repeat step 3 for Dec. 17th in afternoon
 - 4) Maintain vacuum until closing -- keep vacuum on system with pumps off until Monday, Dec. 27th.
- Monday -- Dec. 27th
 - Repeat all tests for Monday, Dec. 20th
 - Leave units under vacuum through Thursday, Dec. 30th.
- Thursday -- Repeat all tests on Thursday, Dec. 30th. Allow system to soak over long weekend.
- January 4 -- Turn on vacuum system
- January 7 -- Take readings as step 3, Dec. 17th.



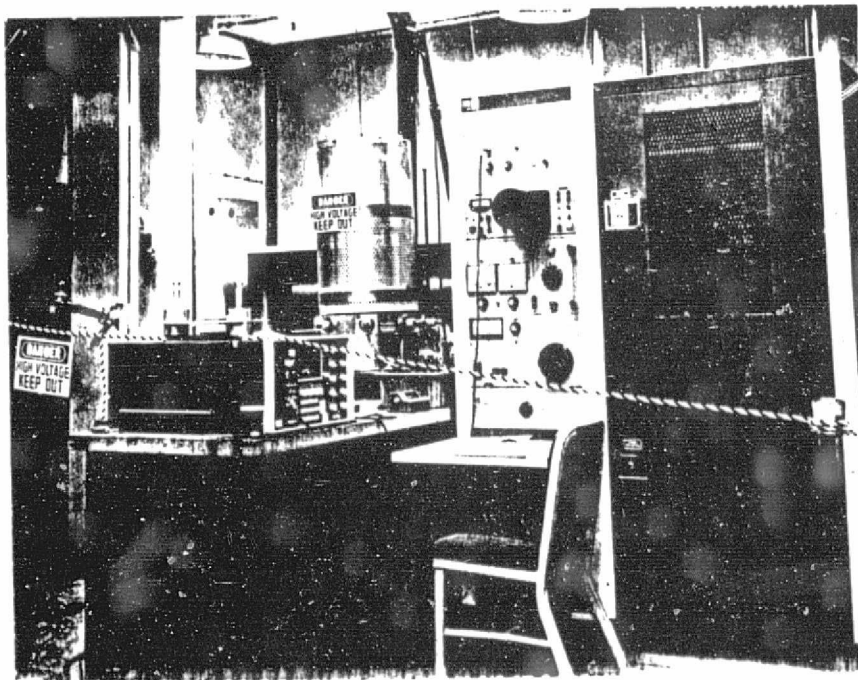
IN BIDDLE CHAMBER



READY FOR VACUUM



VACUUM CHAMBER



ENTIRE INSTRUMENTATION

XVI. SOME BASIC THEORY ON PARTIAL DISCHARGE MEASUREMENTS

Partial Discharges (P. D.) are best defined as "a type of localized discharge resulting from transient gaseous ionization in an insulation system when the voltage stress exceeds a critical value. The ionization is localized over only a portion of the distance between the electrodes of the system."¹ The discharges may be in a void filled with gas or oil inside a potting compound, they may be in inclusions, or they may be along a surface, or about sharp points and edges into the surrounding medium, most commonly air at atmospheric pressure. In fact, the ozone smelled around high voltage equipment is produced by exactly this type of partial discharge into the surrounding air. A more commonly known name for Partial Discharge is Corona. It is called "partial" because it does not extend all the way from electrode to electrode. The pulses are of very short duration, of the order of tens of nanoseconds to microseconds. They are not detectable on a D. C. microammeter or electrometer, and when this type of instrument begins to show a tiny, wavering, average D. C. current, one can be sure that the test sample is already in catastrophic breakdown or suffering very intense, rapidly repeating partial discharge pulses. The detection of individual partial discharge pulses requires sensitive instrumentation to be discussed later.

It is impossible here to go into the detailed discussion as in the excellent book by F. Kreuger,² but some important points might be brought out here: If the void is filled with gas, then Paschen's curve regulates the inception voltage and extinction voltage, as a function of pressure inside the void and the electric field at the void location and the geometric descriptors of the void. (The word "void" is used here for any gas-filled cavity whether bubble or thin, large area gap due to a delamination.) Ionization of individual atoms can occur by collision with an energetic particle carrying the required ionization energy (for instance, 13 electron volts for a hydrogen atom). But to set off a momentary avalanche discharge requires, even at the Paschen minimum pressure, at least several hundred volts across the void.

A.C. versus D.C. testing

The equivalent circuit of a void in a dielectric under A.C. applied voltage is given in Figure 6. The recurrence of internal discharges as a function of applied A.C. voltage³ is shown in Figure 8. As applied voltage v_a across the entire sample rises, so does the voltage across the cavity, v_c . When this reaches the breakdown voltage U^+ a flow of free charge occurs in the cavity, causing a drop in v_c , so that when the discharge extinguishes, v_c across the cavity is down to V^+ . All this occurs in about 10^{-7} seconds². If total applied voltage to the specimen, v_a , is still on the rise, then the v_c will increase again also, until it reaches U^+ again, and there will be another discharge. The field across the cavity is determined by the superposition of the main applied electric field causing fixed polarization charges in the dielectric lining the cavity walls and the field of the free surface charges at the

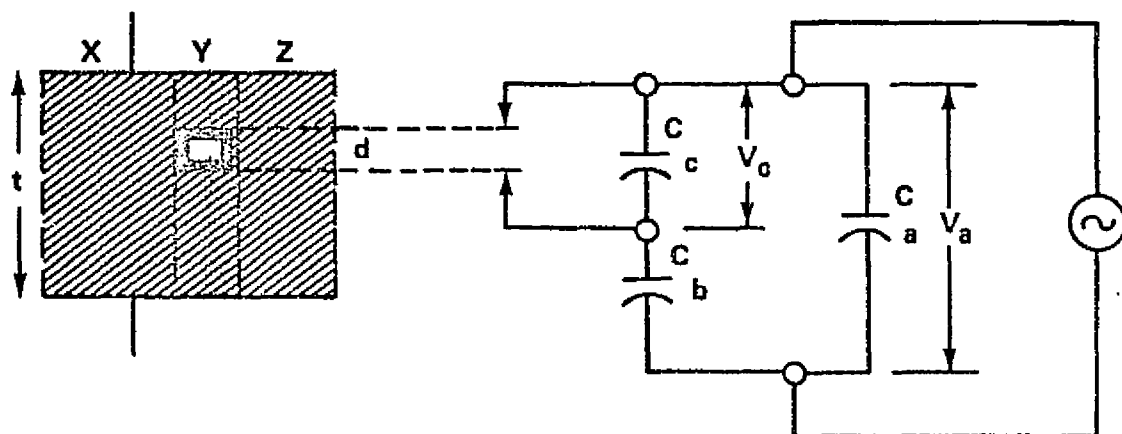


Figure 6. Left: Dielectric with Void.
Right: Equivalent Circuit for AC Partial Discharge Testing.

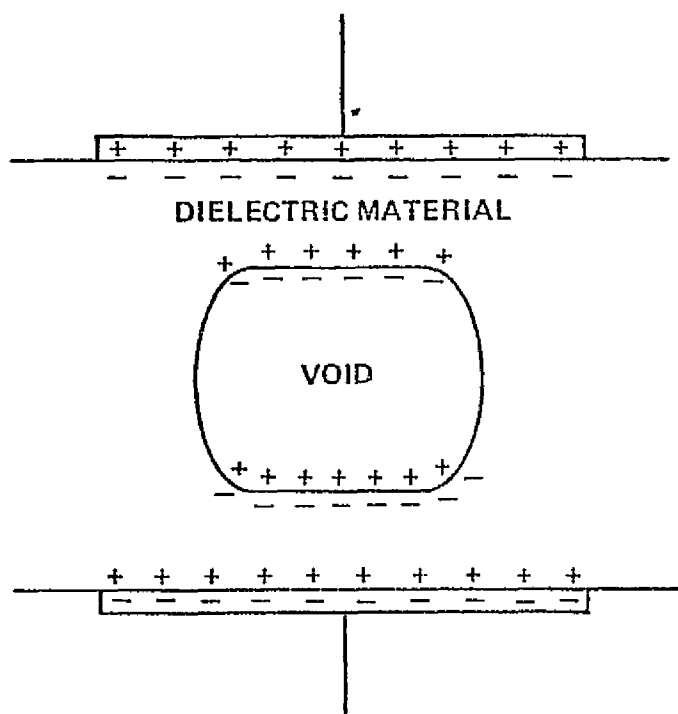


Figure 7. Charge Distribution in a Cavity Just After Discharge

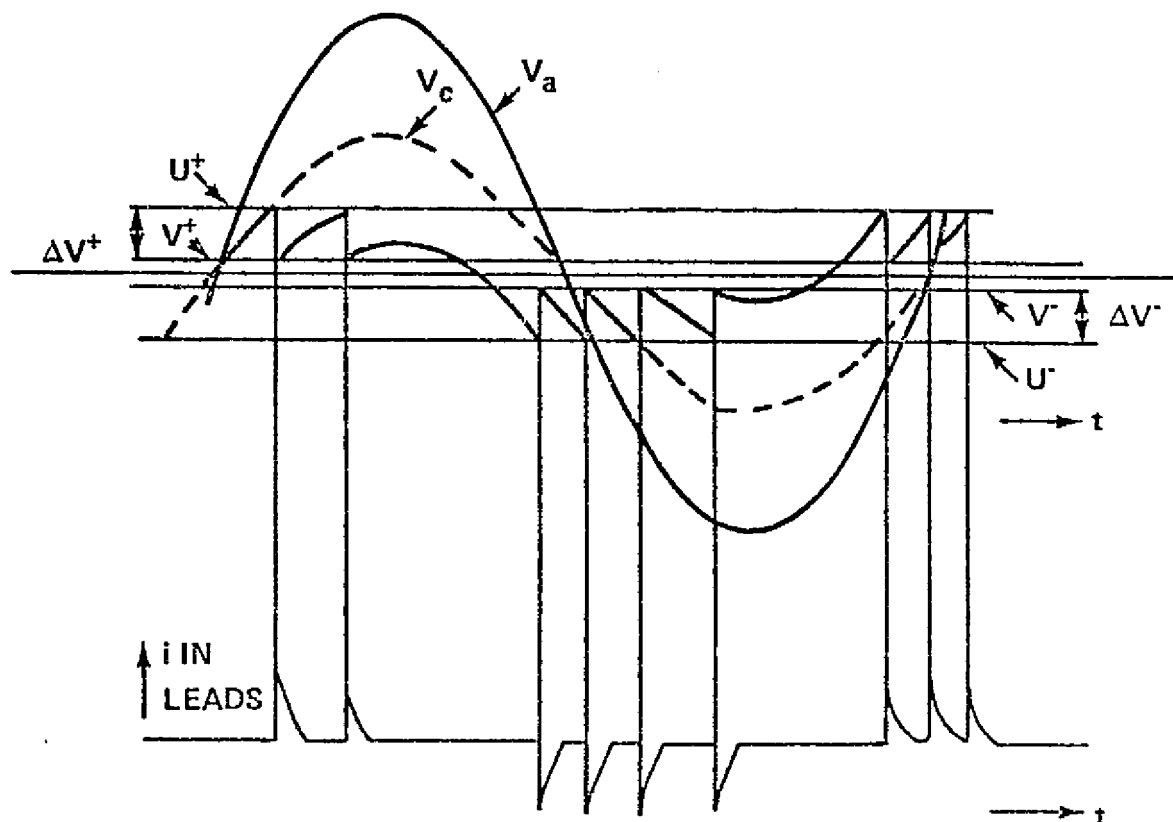


Figure 8. AC Partial Discharge Testing. Applied waveform v_a , voltage across the cavity v_c and current in the leads i , as a function of time t .

inside of the cavity walls, left behind just after the last discharge. Just after the last discharge these fields counteract one another. A qualitative picture of the situation is seen in Figure 7. Just after discharge, the polarization charges and free charges adjacent to one another on the same wall almost neutralize one another until the increasing applied voltage or the change in polarity of the A. C. voltage makes the polarization charges increase in quantity again and predominate again until their field causes another breakdown of the cavity or a second pulse. In the D. C. case, however, one has to wait until more polarization charges in the dielectric medium lining the cavity are placed there by conduction through the dielectric. Since the conductivity of a good dielectric is very low, this takes a long time. Hence, at applied electric fields at which a sample begins to show regularly spaced pulses at A. C.

voltages, discharge pulses at D.C. voltages are few and far between, and might in fact be missed altogether (if integration time is not long enough). Also, the A.C. voltages induce charge transfer through the dielectric test sample at a high rate. This rate is negligible for quiescent D.C. voltage. This rate heating and charge transfer make breakdown of flawed regions inside the dielectric more likely. Thus, the observable onset of discharge pulses occurs at higher voltage for D.C. than for peak A.C. applied voltage. Moreover, the pulses on D.C. are irregularly occurring with time rather than synchronized with the applied A.C. frequency. Observation on D.C. must therefore be made with a storage oscilloscope and nuclear counters. (The equivalent circuit of the test sample on D.C. testing can be pictured as having high resistances parallel about all capacitors in Figure 6.) Ripple voltages superimposed on direct voltage will increase the D.C. discharge repetition frequency.²

In short, D.C. measurements are much more difficult and more time consuming to make, especially where random interference pulses from disturbances on the electric lines or from electromagnetic waves despite shielding, can easily be mistaken for discharge pulses. On the other hand, D.C. measurements are much less destructive to the sample than A.C., which already at inception sets off thousands of pulses (for 60 hertz testing), each pulse doing a little damage. In general, samples should be tested under the same conditions under which they will be used.

Several questions arise and need to be dealt with as to the circuit arrangements for detecting the tiny P.D. pulses; general outlines of basic circuitry are given in ASTM D 1868-73. More specifically:

- (1) What is the detection impedance Z that translates the small current surges in the test specimen leads into measurable voltage pulses?
 - a. One can use a resistor R in parallel with a small capacitance C ; this RC network can be the feedback network of a charge-sensitive operational amplifier, the C acting as an integrating capacitor for the charge. The voltage pulse across this combination will be unidirectional.
 - b. One can use a tuned ICR input network, which is the method used by the James G. Biddle Co. P.D. Detection System used in this experiment. The corona impulse sets off shock

oscillations, the first negative half of which is integrated and amplified.

- (2) What type of preamplifier is used and what are its input characteristics and its own noise levels, so as to permit the tiny fast voltage pulses to pass through without attenuation or obliteration?
- (3) What is the circuit sensitivity of different arrangements of the circuit components? Circuit sensitivity is defined as the fraction of the terminal corona-pulse voltage that appears across the detection impedance Z for measurement.

This has to be answered by a proper calibration method preceding the testing with each new test sample inserted.

- (4) How does the above-mentioned "terminal corona-pulse voltage" or better, how does the apparent terminal charge-content of the pulse indicate what is really going on in an internal cavity? In other words, how do the relative sizes of cavity and dielectric thickness influence what magnitude of charge appears at the test sample terminals, corresponding to what goes on in the void?
(sample sensitivity?)

One can try to answer this by either A) an equivalent circuit, or B) the actual physical picture. Some of both approaches are presented here.

- A) The equivalent circuit of a corona-causing cavity in a slab of dielectric under A.C. conditions is repeated in Fig. 9 and under D.C. conditions is shown in Figure 10.

Here C_a , C_b and C_c represent the capacitances of the dielectric free from cavities, the dielectric in series with the cavity, and the cavity itself respectively. Similar subscript letters are used with the parallel resistances R_a , R_b and R_c . The physical reason for the greater complexity under D.C. conditions is the following:

In the A.C. case, on the first quarter cycle there are as many pulses as whole number multiples of the corona inception voltage to the peak voltage. Then as the voltage drops and increases in the other direction the discharges inside the bubble occur in the opposite direction, so that the free surface charge inside the bubble is discharged over and over again in

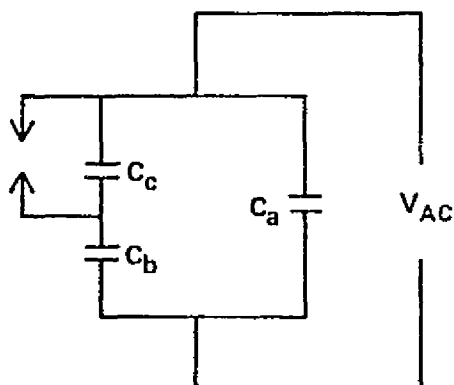


Figure 9

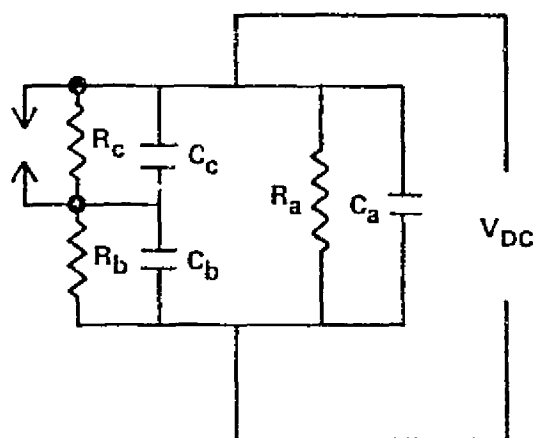


Figure 10

alternate directions. The pulses appear well-synchronized on the Lissajous figure of the A.C. frequency on the oscilloscope screen and are therefore easily observed. In the D.C. case, as one first manually raises the voltage to the desired level, one probably misses observing the pulses that occurred during the voltage increase, and once that the desired steady, unidirectional voltage level is reached, then conduction through the dielectric is needed to recharge one and the same side of the internal surface of the void that has just been discharged.

Hence the R's enter into the equivalent circuit, and hence the energy content, the charge content, the repetition rate of pulses on D.C. all involve the equivalent resistances as well as the equivalent capacitances. Moreover there is the added complication that at the true discharge inception voltage, which is the lowest voltage at which discharges can occur in the void according to Paschen's curve, the time between successive discharges is extremely long, and so the discharge inception voltage is experimentally not observable. As the applied voltage is increased to where one observes a few countable pulses per minute, the applied voltage V is already several times the inception voltage V_i . (The capitalized

voltages V and V_i refer here to the externally applied voltages that correspond to the voltages v and v_i across the actual internal cavity).

An analysis that is based on the above ideas⁴ predicts the following relationships:

At the discharge inception voltage, the apparent discharge magnitude q is given by

$$q = \left(C_a + \frac{C_b C_c}{C_b + C_c} \right) \cdot \frac{C_b}{C_a + C_b} \cdot \frac{R_c}{R_b + R_c} \cdot V_i \quad (1)$$

Hence the energy W dissipated by the discharge is

$$W = \frac{1}{2} q V_i \frac{R_c}{R_b + R_c} \cdot \frac{C_b + C_c}{C_b} = \frac{1}{2} q V_i \gamma \quad (2)$$

where

$$\gamma = \frac{R_c}{R_b + R_c} \cdot \frac{C_b + C_c}{C_b}$$

and is slightly larger than 1. Since one really works at $V = nV_i$, the energy dissipated per pulse can be written

$$W = \frac{1}{2} q \frac{V}{n} \gamma \quad (3)$$

but is still the same as at discharge inception voltage. The number of discharges occurring per unit time or the discharge repetition rate, f , is

$$f = \frac{-qV\varphi}{2\epsilon\epsilon_0 n \ln(1 - 1/n)} = \frac{qV\varphi}{2\epsilon\epsilon_0}, \text{ if } n \gg 1 \quad (4)$$

where φ is the conductivity, ϵ the permittivity of insulating material and ϵ_0 the permittivity of free space.

Two or three predictions can be made from these equations. It is seen from equation (1) that the relative magnitudes of C_c , C_a , and especially C_b , which is the capacitance of the dielectric in series with the cavity, greatly influence the amount of apparent charge content q in a given pulse, that appears at the output terminals of the test sample. In other words, even if the test samples are similar in their gross features and even if the circuit sensitivity is the same, then one should still expect different charge content of the output pulses depending on the relative size of the flaw and the thickness of the dielectric that it is buried in.

Another feature emerges from equation (4). It is seen that the repetition rate varies directly with the conductivity of the insulating material. The conduction process in high polymers is not a simple process: Conductivity decreases with time after application of voltage. Theoretically the conductivity in polymers is influenced by trapping of the few free charge carriers and of the injected electrons, at shallow and at deep traps. This is a time-dependent process. Also space-charge effects enter in as charge is injected into the polymer, and interface at the electrodes add to the complications. The entire armory of Solid State Physics must be wheeled out for theoretical treatment of high polymer conduction,⁵ similar to semi-conductor treatment.

The prediction from equation (3), that there simply are more and more pulses as the voltage is raised, all of the same charge and energy content has not been found to be true, in general, in experiments on D.C. Partial Discharge conducted by the author: as D.C. voltage is increased the percentage of more energetic pulses often also increases. Perhaps this means that in a given test sample there are many flaws and tiny voids. So perhaps, as voltage is increased, discharges are energized in more and more sites of imperfection, rather than all coming from one site at ever-increasing repetition rate.

- B) The Dielectric System Model⁶ which is presented as an alternate approach, refers back to Figure 6. It is a simplified approach and uses a pancake shaped void rather than the more realistic and more difficult oblate spheroid shape. It is strictly applicable only under A.C. applied voltage conditions

since it does not take the conductivities into account. However, as a first clarification and for order of magnitude calculations it is useful, since one does not get completely bogged down in mathematical complications.

In a pancake void with axis parallel to the electric field, the electric field within the void is k times the field within the dielectric, where k is the dielectric constant ($\epsilon = k$). The fringing fields and a possible field discontinuity are ignored here, and in the regions X, Y, Z in the Figure 6, the following is the case:

In the regions X and Z the capacitance per unit area is

$$C_a = k\epsilon_0/t \quad (5)$$

where t is the thickness.

In region Y, the capacitance of the void C_c and of the remaining material C_b

$$C_c = \epsilon_0/d \quad C_b = k\epsilon_0/(t-d) \quad (6)$$

where d is the thickness of the void. The capacitance of the entire portion Y

$$C_Y = \frac{k\epsilon_0}{t + d(k-1)} \quad (7)$$

The electric fields in portion Y, for the capacitor plates maintained at voltage V , are, for the field within and without the void

$$E_m = k E_{out} \quad E_{out} = V/(t + d(k-1)) \quad (8)$$

The fields in part X and Z are V/t .

It is now possible to find the free charge distribution in the capacitor plates. This will not be uniform: In the regions of

no void, the charge per unit area is

$$Q = (k\epsilon_0/t) \cdot V \quad (9)$$

In the section with the void the distribution is

$$Q = (k\epsilon_0/[t(1 + n(k - 1))]) \cdot V \quad (10)$$

where $n = d/t$.

When the void discharges to an effective zero field in the void, then the change in the free charge observed in the capacitor plates is, per unit area

$$\Delta Q_f = \frac{k\epsilon_0 V}{t} \left[1 - \frac{1}{1 + n(k - 1)} \right] \quad \frac{pc}{m^2} \quad (11)$$

The corresponding charge transfer within the void is then per unit area

$$Q = k\epsilon_0 V/(t - d) \quad (12)$$

It is useful now to make a calculation as to what order of magnitude of charge change to expect for the particular geometries and sizes of potting thickness and bubble sizes in the IUE Vidicon tube dummy test samples.

The sort of dimensions one deals with is seen in Figure 2. At the most convoluted portion the depth of potting is $(3.312'' - 2.024'')/2$. This is about 0.65" or 1.6 cm. Assume a discharge inception voltage, at atmospheric pressure, across a void 1 mm in diameter and 1 mm deep, of 16,000 volts, V, applied field. This is not unreasonable, as seen from the several Paschen curves⁶ enclosed here. If one now substitutes in equation (11), one obtains if one uses $k = 4$

$$A \times \Delta Q_f = \frac{4 \times 8.8 \times 10^{-12} \times 16,000}{0.016} \left[1 - \frac{1}{1 + \frac{0.1}{1.6} \times 3} \right] \times \frac{11 \times 10^{-6}}{4} \quad pc$$

This amounts to a change in free charge of about 4 picocoulombs. The result depends very sensitively on the relative void to dielectric size, of course.

The point of this calculation is that one must not, in this experiment, ignore the changes in charge and in pulse counts at the lower end of the Biddle equipment sensitivity. One must, it appears, pay close attention as to what happens in the 1 to 10 picocoulomb range, not only look for the 60 and 120 picocoulomb pulses.

As stated by another investigator⁷: "the sensitivity of p.d. measurements is high for samples of small thickness corresponding to a given cavity diameter. For example, for a 50 μm diameter cavity in a 200 μm thick sample, the discharge magnitude is 0.5 pc."

Figures 11a, 11b, 12 and 13 are enclosed for ease of analysis and as a calculation resource.^{2,6,7} Figures 12 and 13 have had the voltages increased by 20% to compensate for the difference between iron electrodes used by Paschen and the case of interest here where the void walls are insulating materials.⁶

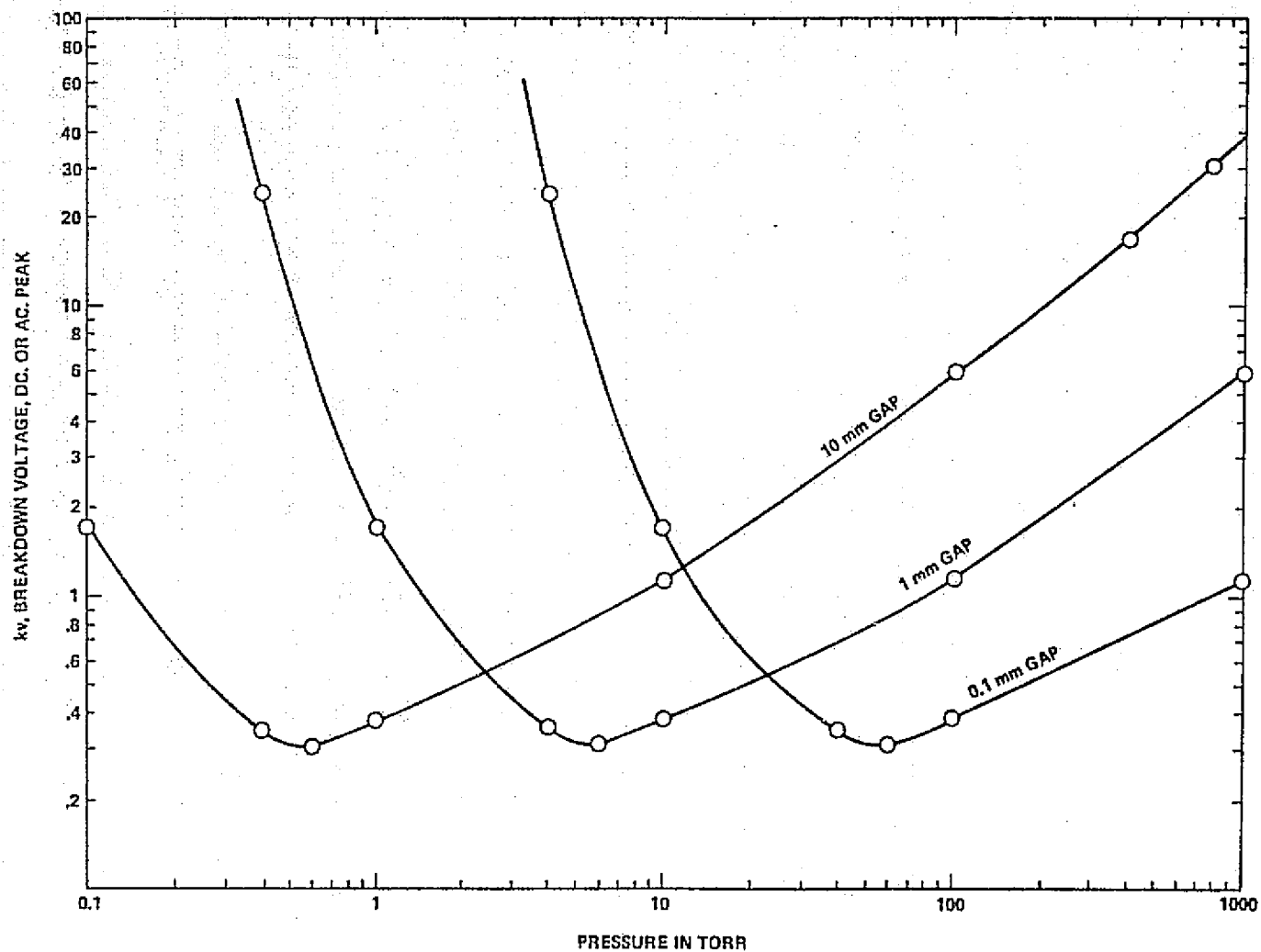


Figure 11a. Paschen's Original Curves. Breakdown Voltage in Air as a Function of Pressure. (Iron Electrodes)

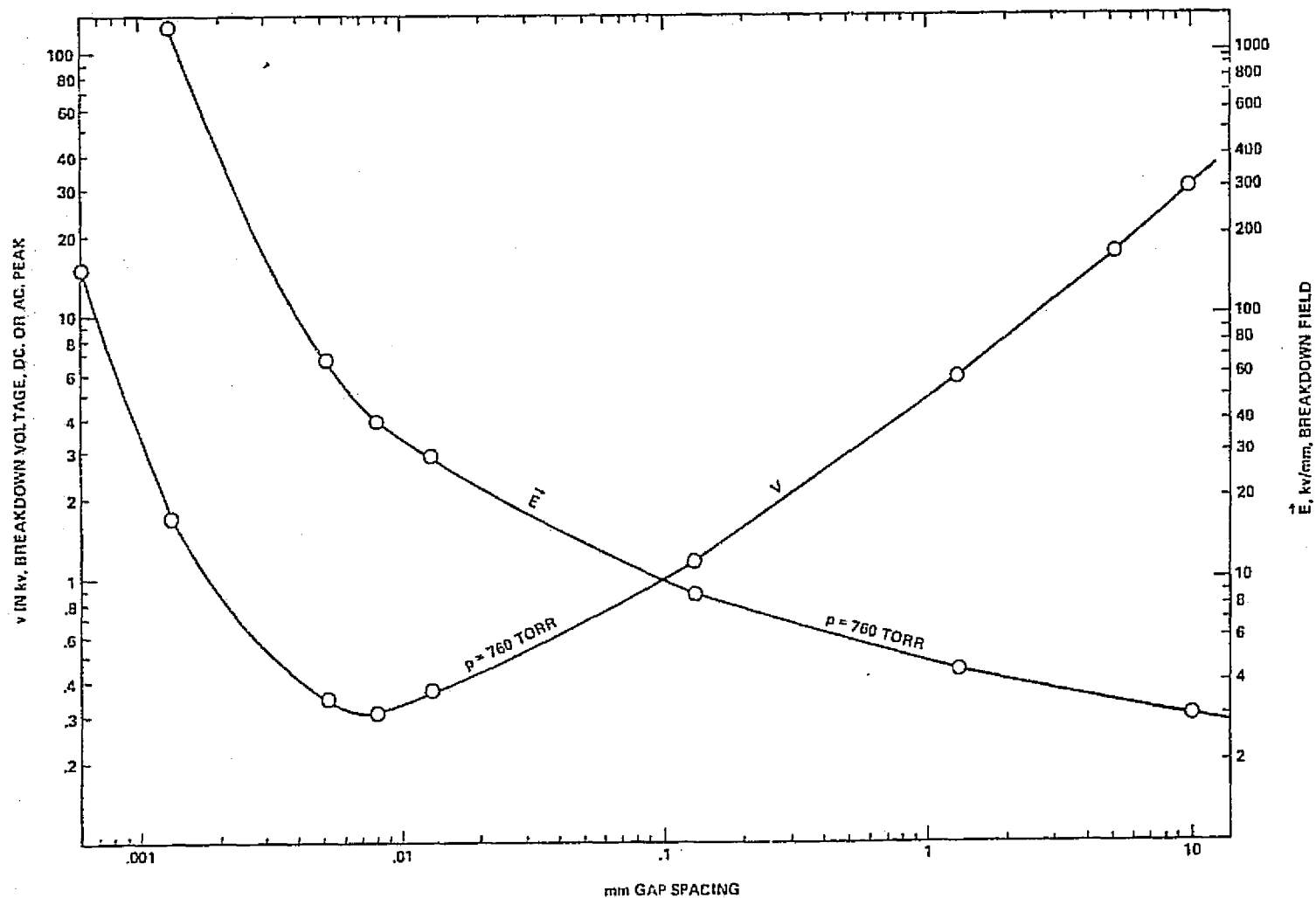


Figure 11b. Paschen's Curve, V. Field Strength Curve, E. (Iron Electrodes)

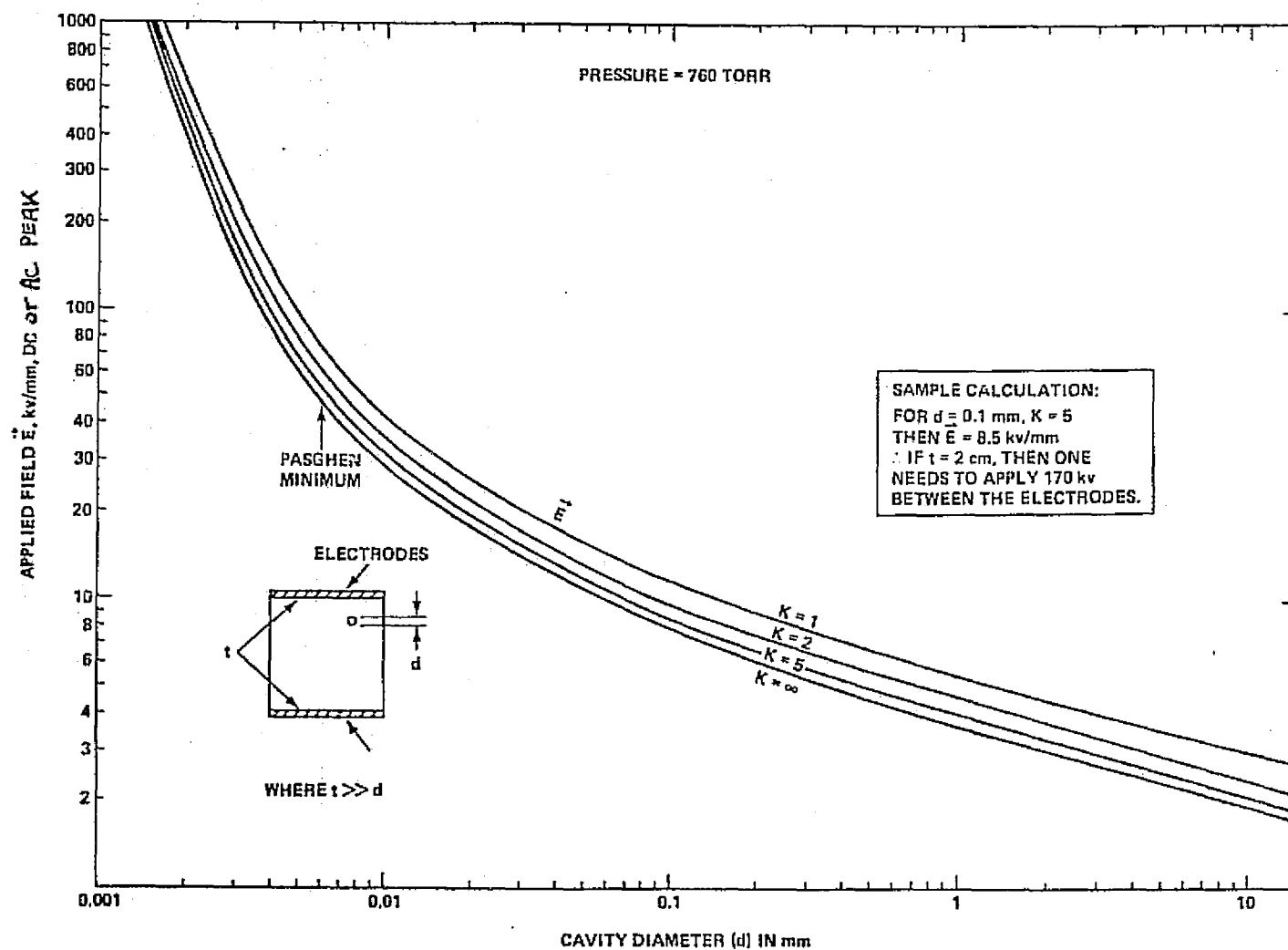


Figure 12. Corona Inception Stress Within the Dielectric, in kv/mm D.C., Versus Void Size, for Different Dielectric Constants (k) for Spherical Voids.

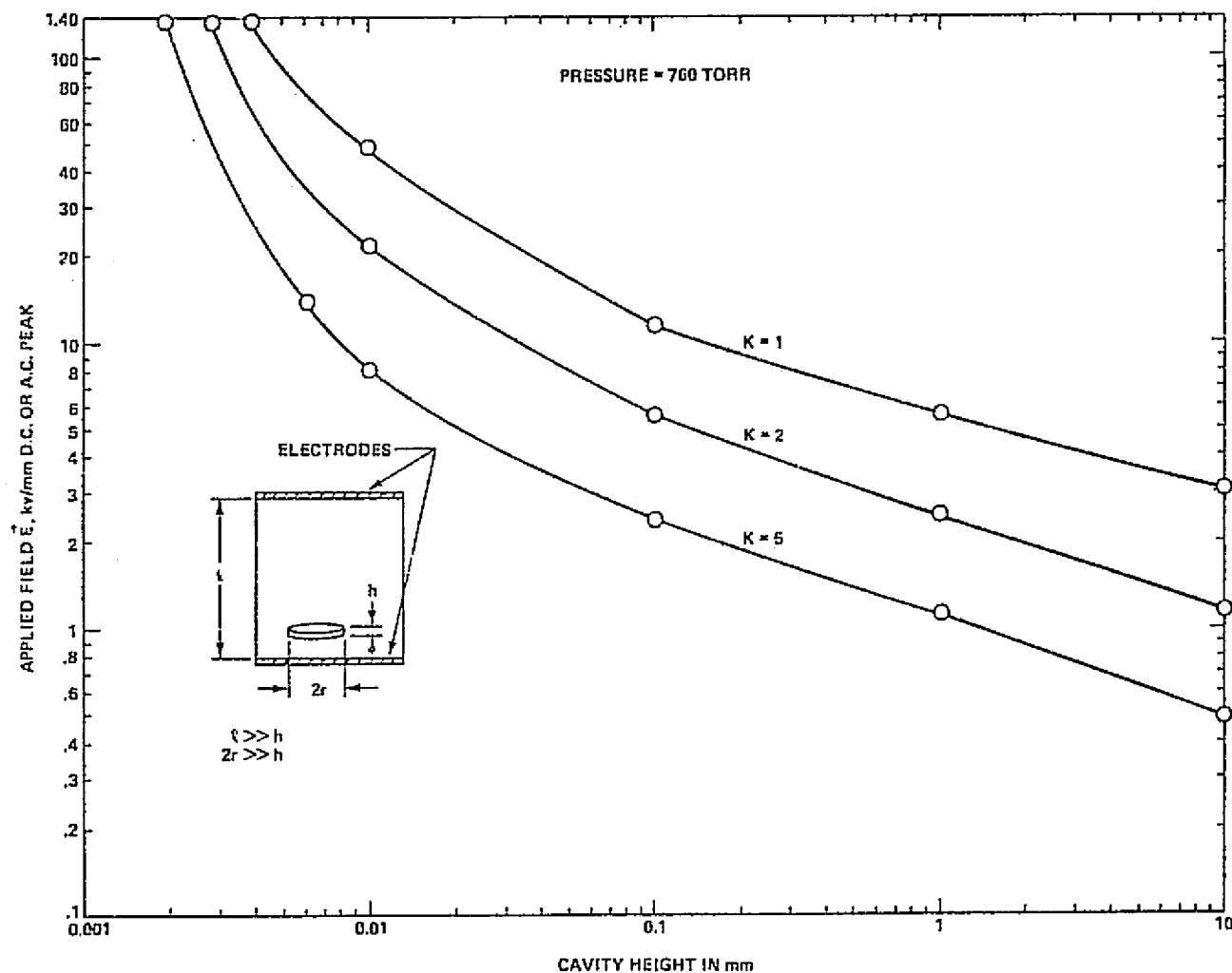



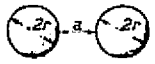

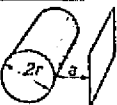
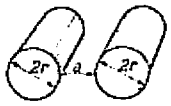
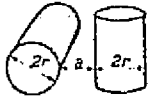

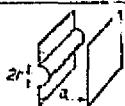
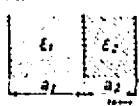


Figure 13. Corona Inception Stress Within the Dielectric, in kV/mm D.C., Versus Void Height of a Cylindrical Void; Height Parallel to the \vec{E} Field; for Different Dielectric Constants (k).

TABLE I Maximum Field Strength E with a Potential Difference U Between the Electrodes, for Different Electrode Configurations

Configuration		Formula for E	Example
Two parallel plane plates		$\frac{U}{a}$	$U = 100 \text{ kV}, a = 2 \text{ cm},$ $E = 50 \text{ kV/cm.}$
Two concentric spheres		$\frac{U}{a} \cdot \frac{r+a}{r}$	$U = 150 \text{ kV}, r = 3 \text{ cm}, a = 2 \text{ cm},$ $E = 125 \text{ kV/cm.}$
Sphere and plane plate		$0.9 \frac{U}{a} \cdot \frac{r+a}{r}$	$U = 200 \text{ kV}, r = 5 \text{ cm}, a = 3 \text{ cm},$ $E = 58.5 \text{ kV/cm.}$
Two spheres at a distance a from each other		$0.9 \frac{U}{a} \cdot \frac{r+a/2}{r}$	$U = 200 \text{ kV}, r = 5 \text{ cm}, a = 12 \text{ cm},$ $E = 33 \text{ kV/cm.}$
Two coaxial cylinders		$\frac{U}{2.3 r \lg \frac{r+a}{r}}$	$U = 100 \text{ kV}, r = 5 \text{ cm}, a = 7 \text{ cm},$ $E = 22.9 \text{ kV/cm.}$
Cylinder parallel to plane plate		$0.9 \frac{U}{2.3 r \lg \frac{r+a}{r}}$	$U = 200 \text{ kV}, r = 5 \text{ cm}, a = 10 \text{ cm},$ $E = 32.8 \text{ kV/cm.}$
Two parallel cylinders		$0.9 \frac{U/2}{2.3 r \lg \frac{r+a/2}{r}}$	$U = 150 \text{ kV}, r = 6 \text{ cm}, a = 20 \text{ cm},$ $E = 11.5 \text{ kV/cm.}$
Two perpendicular cylinders		$0.9 \frac{U/2}{2.3 r \lg \frac{r+a/2}{r}}$	$U = 200 \text{ kV}, r = 10 \text{ cm}, a = 10 \text{ cm},$ $E = 22.2 \text{ kV/cm.}$
Hemisphere on one of two parallel plane plates		$\frac{3U}{a}; (a \gg r)$	$U = 100 \text{ kV}, a = 10 \text{ cm},$ $E = 30 \text{ kV/cm.}$
Semicylinder on one of two parallel plane plates		$\frac{2U}{a}; (\pi \gg r)$	$U = 200 \text{ kV}, a = 12 \text{ cm},$ $E = 33.3 \text{ kV/cm.}$
Two dielectrics between plane plates ($a_1 > a_2$)		$\frac{U \epsilon_1}{a_1 \epsilon_2 + a_2 \epsilon_1}$	$U = 200 \text{ kV}, \epsilon_1 = 2, \epsilon_2 = 4, a_1 = 6 \text{ cm}, a_2 = 5 \text{ cm},$ $E = 11.8 \text{ kV/cm.}$

From Handbook of Materials and Techniques for Vacuum Devices
by Walter H. Kohl, Reinhold Publ. Co, 1967, p 583

XVII RESULTS

A. LIFE TESTS IN HIGH VACUUM: UNDER DIRECT VOLTAGE CONDITIONS

Since the Life tests in vacuum are of the greatest interest, and since the surface effects are suppressed the most in high vacuum, these Life tests are analyzed first. In other words, the surface corona does not becloud the effects from bulk flaws, which is what the experiment was meant to discover. Thus the Life test lends itself to analysis more kindly. Although the sequence of events is presented earlier, a copy of the time-table during the first few weeks of the Life test is inserted here for easy reference.

For any given sample, the histograms of number of pulses N versus charge-content Q in picocoulombs are plotted in the following succession:

1. In the Biddle enclosure at atmospheric pressure, with smooth central shaft and corona ball making contact to the negative high voltage electrode. This data is plotted at 3, 6, 9, 12, 15 kilovolts.
2. Configured in the vacuum chamber, but still at atmospheric pressure, shaft and ball contacting the negative HV electrode. This is plotted at 15 kv only, for most units. (VAC. FIXTURED)
3. In vacuum, at less than 10^{-5} torr during the daytime working hours, for 12 weeks, at 6, 9, 12, 15 and later at also 18 and 20 kv D.C. It is to be remembered that between once-weekly P.D. tests, 15 kv DC was applied to all samples (except #5) for 8 hours/day for 5 days/week.
4. Back to atmospheric pressure with room air at the end of 12 weeks.
5. For some of the units there was subsequent reevacuation, back to atmospheric pressure with dry nitrogen, then a test under transformer oil in the Biddle enclosure.

The set of histograms for any one sample is presented. Then that sample is discussed. At the very end general conclusions are summarized.

For easier referencing descriptions and sketches of each experimental dummy tube are also included.

LIFE DATE	TEST TIME	PRESSURE	NOTES
9/17/76	1650	6×10^{-6} TORR	TURNUED OFF FOR WEEKEND
9/20/76	0800	3 TORR	START UP VAC. SYS.
9/20/76	1125 1645	3×10^{-5} TORR 1.5×10^{-5} TORR	15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/21/76	0745 0825 1640	1 TORR 3×10^{-5} TORR 4×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/22/76	0745 0835 1640	8×10^{-1} TORR 1×10^{-5} TORR 4×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/23/76	0740 0820 1640	7×10^{-1} TORR 2×10^{-5} TORR 3×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/24/76	0735 0825 0945 1520 1635 1640	6×10^{-1} TORR 2.5×10^{-5} TORR 4×10^{-6} TORR 4×10^{-6} TORR 3×10^{-5} TORR 3×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF BIDDLE TESTS STARTED 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/27/76	0745 0820 1640	1.5×10^0 TORR 3×10^{-5} TORR 3×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/28/76	0745 0820 1640	6×10^{-1} TORR 2×10^{-5} TORR 4×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/29/76	0740 0820 1640	5×10^{-1} TORR 3×10^{-5} TORR 2×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
9/30/76	0950 1005 1930	2×10^{-1} TORR 2×10^{-5} TORR 2×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF
10/ 1/76	0755 0830 0940 1635	4×10^{-1} TORR 2×10^{-5} TORR 5×10^{-6} TORR 4×10^{-6} TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF BIDDLE TESTS STARTED VAC. SYS. OFF

LIFE DATE	TEST TIME	PRESSURE	NOTES
10/ 4/76	0745 0820 0905* 0925 0930 1640	9 X 10 ⁻¹ TORR 2 X 10 ⁻⁵ TORR — 7 X 10 ⁻² TORR 10 ⁻⁵ TORR 3 X 10 ⁻⁶ TORR	STARTUP VAC. SYS. 15kv SUPPLY ON POWER FAILURE* POWER BACK ON 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
10/ 5/76	0740 0820 1640	4 X 10 ⁻¹ TORR 2 X 10 ⁻⁵ TORR 3 X 10 ⁻⁶ TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
10/ 6/76	0740 0815 1700	4 X 10 ⁻¹ TORR 2 X 10 ⁻⁵ TORR 3 X 10 ⁻⁶ TORR	STARTUP VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
10/ 7/76	0745 0815 1650	3 X 10 ⁻¹ TORR 2 X 10 ⁻⁵ TORR 3 X 10 ⁻⁶ TORR	START VAC. SYS. 15kv SUPPLY ON 15kv SUPPLY OFF VAC. SYS. OFF
10/ 8/76	0745 0815	3 X 10 ⁻⁶ TORR 2 X 10 ⁻⁵ TORR	START VAC. SYS. 15kv SUPPLY ON

*KVAC SYSTEM OFF WITHIN 1 MINUTE OF FAILURE.

SN01

IUE DUMMY TUBE

MFGR. DATE: JUNE 23, 1976

- ① PRIMED ALL SURFACES WITH WOOSLEY METALAST PRIMER
USED SOLITHANE FORMULATION #2
VACUUM FOR 1 HR.
CURE: ROOM TEMP. 4 HOURS THEN +50°C FOR 16 HRS.
2 POURS: 1ST POUR 2/3 FULL; 2ND FINISHED TO TOP.
- NO PINCH OFF CAPS ADDED TO DUMMY TUBE BEFORE ENCAPSULATION
- NO CONDUCTIVE CONFORMAL COATING OR BRASS TAB ON MOLDED SURFACE

- ② USED 15 CU. CM. OF SOLITHANE #6 TO BOND CENTER OF MOLDED ASSY. TO ALUMINUM CYLINDER. MFGR. DATE: JULY 2, 1976

- ③ X-RAYED AT BLDG 6 ON JULY 12: NO CONCLUSIVE RESULTS

CAPACITANCE OF UNIT WITH BALL & ROD ELECTRODE & INNER CYLINDER COVERED WITH SOLITHANE; 8/5/76 - 63pf

STATUS.

SN02

IUE DUMMY TUBE

MFGR DATE: JUNE 24, 1976

- ① - PRIMED ALL * SURFACES WITH WOOSLEY METALAST PRIMER
- USED SOLITHANE FORMULATION #2
- VACUUM FOR 1 HOUR
- CURE: R.T. 4 HRS, THEN +50°C FOR 16 HRS
- 2 POURS: 1ST POUR 2/3 FULL. SECOND FINISH TO TOP
- NO PINCH OFF CAPS ON DUMMY TUBE
- ② - TEMPERATURE CYCLING: 1ST CYCLE -10°C TO +50°C
2ND CYCLE -20°C TO +60°C
3RD CYCLE -5 °C TO +80°C
4TH CYCLE -50 ° TO +80°C

DEFECTS NOTED:

AFTER 3RD CYCLE: SMALL CRACKS (2) IN CONVOLUTED AREA WHICH WAS NOT PRIMED.

AFTER 4TH CYCLE: 3 SMALL CRACKS IN CONVOLUTED AREA WHICH WAS NOT PRIMED + SMALL AMOUNT DELAMINATION THERE;
LARGE DELAMINATION

*(DID NOT PRIME 90° SECTOR OF CONVOLUTED AREA.)

SN03

IUE DUMMY TUBE

MFGR. DATE: JUNE 25, 1976

- ① PRIMED ALL SURFACES WITH WOOSLEY METALAST PRIMER
 - USED HYSOL XTU-0021 RESIN 50 P.B.W.
XHD-0165 HARDNER 50 PBW
 - VACUUM FOR 30 MIN. (POURED UNDER VACUUM)
 - ROOM TEMP. 4 HRS 16 HRS AT 50°C
 - PINCH OFF CAPS ADDED TO DUMMY TUBE BEFORE ENCAPSULATION
- ② - TEMPERATURE CYCLING: NONE
- ③ - CONDUCTIVE COATING OF SOLITHANE #6 + 5% B.W. CARBON BLACK WITH BRASS TAB ADDED TO DUMMY TUBE BEFORE ENCAPSULATION
- ④ X-RAYED AT BLDG 6 7/12 NO VISIBLE DEFECTS
XEROGRAM AT WASH. HOSP. CENTER 7/13
- ⑤ - USED 7.6 CU. CM. OF SOLITHANE #6 TO BOND CENTER OF MOLDED ASSEMBLY TO ALUMINUM CYLINDER
MANUF. DATE: JULY 8, 1976

STATUS

SN04

IUE DUMMY TUBE

MFGR. DATE: JUNE 29, 1976

- ① - PRIMED ALL SURFACES WITH WOOSLEY METALAST PRIMER
 - ENCAPSULATED WITH SOLITHANE FORMULATION #2
 - VACUUM FOR 1 HOUR
 - CURE: R.T. FOR 4 HRS: THEN +50°C FOR 16 HRS.
 - 2 POURS: 1ST POUR, 2/3 FULL; SECOND POUR, FINISH TO TOP
 - PINCH-OFF CAPS (2) ADDED TO DUMMY TUBE BEFORE ENCAPSULATION
- ② - TEMPERATURE CYCLING: 1ST CYCLE: -10°C TO +50°C
2ND CYCLE: -20°C TO +50°C

DEFECTS NOTED:

AFTER SECOND CYCLE:

CRACKING OCCURRED AT ONE PINCH-OFF CAP AS SHOWN ON FIGURE ON BACK OF CARD.

SN05

IUE DUMMY TUBE

MFGR. DATE: JULY 1, 1976

- ①
 - PRIMED ALL SURFACES WITH WOOSLEY METALAST PRIMER
 - ENCAPSULATED WITH SOLITHANE FORMULATION 2
 - VACUUM FOR ONE HOUR
 - CURE: ROOM TEMP. 4 HRS; THEN +50°C FOR 16 HRS
 - 2 POURS: 1ST POUR 2/3 FULL; SECOND, FINISH TO TOP
 - 2 PINCH OFF CAPS ADDED TO DUMMY TUBE BEFORE ENCAPSULATION

- ②
 - TEMPERATURE CYCLING: ONE CYCLE: -10°C TO +50°C

DEFECTS NOTED: BEFORE ANY CYCLING:

3 LARGE BUBBLES; SEVERAL SMALL ONES
ONE ON LARGEST CONVOLUTED FLANGE
TWO ON INSIDE SURFACE OF POLYSAND RING
SEVERAL SMALL BUBBLES ON INSIDE SEAM OF SMALL CONVOLUTED
FLANGE AND NEAR LARGE BUBBLES ON POLYSAND RING

SN06

IUR DUMMY TUBE

MFGR. DATE: JULY 2, 1976

- ①
 - ENCAPSULATED WITH SMRD 432 HEATED TO +50°C
 - PULLED VACUUM ON MATERIAL 2 HRS
 - POURED ENTIRELY UNDER VACUUM
 - CURED AT 110°C FOR 16 HRS, THEN TURNED OFF HEAT & ALLOWED TO COOL ANOTHER 42 HRS BEFORE REMOVAL FROM MOLD.
 - TWO PINCH-OFF CAPS ADDED TO DUMMY TUBE.

- ②
 - TEMPERATURE CYCLING: NONE

- ③
 - CONDUCTIVE COATING OF SOLITHANE FORM #6 + 5% BY WT. OF CARBON BLACK & BRASS TAB ADDED TO MOLDED SURFACE

- ④
 - USED 7.6 CU. CM. OF VERSAMID 140 & EPON 828 50/50 PARTS BY WT. TO BOND CENTER OF MOLDED ASSY TO ALUMINUM TUBE.

MFGR. DATE: JULY 9

- ⑤
 - XEROGRAM AT WASH. HOSP. CENTER ON JULY 13
(NO NOTICEABLE DEFECTS)

STATUS: CANDIDATE FOR TEST 7/23/76

SN07

IUE DUMMY TUBE

MFGR. DATE: JULY 1, 1976

- ①
 - PRIMED ALL SURFACES WITH WOOSLEY METALAST PRIMER
 - USED SOLITHANE FORMULATION #2
 - VACUUM 1 HR.
 - CURE: 4 HRS R.T.; 16 HRS +50°C
 - 2 POURS: 1ST 2/3 FULL; 2ND FILL TO TOP
 - 2 PINCH-OFF CAPS INSTALLED BEFORE ENCAPSULATION
- ② TEMPERATURE CYCLING: NONE (NO DEFECTS)
- ③
 - CONDUCTIVE COATING OF SOLITHANE FORM. #6 + 5% BY WT.
 - CARBON BLACK AND BRASS TAB ADDED TO MOLDED SURFACE
- ④
 - USED 7.6 CU. CM. OF SOLITHANE #6 TO BOND CENTER OF MOLDED SURFACE TO ALUMINUM CYLINDER.

MFGR. DATE: JULY 9

⑤

STATUS: CANDIDATE FOR TEST 7/23/76

SN08A

IUE DUMMY TUBE

MFGR. DATE: JULY 18, 1976

- ①
 - PRIMED ALL SURFACES WITH WOOSLEY METALAST PRIMER
 - USED CONAP EN-11 100 PBW RESIN + 55 PBW CATALYST
 - VACUUM 1 HR
 - CURED: 64 HRS AT 50°C
 - INSTALLED TWO PINCH-OFF CAPS BEFORE ENCAPSULATION
 - ② TEMP. CYCLING (NONE)
 - ③ CUT IN TWO DEFECTS (SEE X-RAYS) + (OVER)
 - ④
 - CONDUCTIVE COATING OF SOLITHANE #6 + 5% BY WT.
 - CARBON BLACK & BRASS TAB ADDED TO TUBE MOLDED SURFACE.
 - ⑤
 - USED 7.6 CU. CM. OF SOLITHANE #6 TO BOND CENTER OF MOLDED ASSY. TO ALUMINUM CYLINDER
- MFGR. BY JULY 25
- CAPACITANCE: 59 pf (WITH METAL CENTER PIECE INSTALLED)

MFGR. DATE: JULY 8, 1976

- 5

STATUS:

MFGR. DATE: JULY 9, 1979

- 4

39

SN10

IUE DUMMY TUBE

MFGR. DATE: JULY 12, 1976

- ①
 - PRIMED ALL SURFACES WITH WOOSLEY METALAST PRIMER
 - ENCAPSULATED WITH CONAP EN-12 100 PBW RESIN; 95 PBW CATALYST
 - POURED UNDER VACUUM
 - CURED AT +50°C FOR 24 HRS.
 - ADDED 2 PINCH-OFF CAPS TO DUMMY TUBE BEFORE ENCAPSULATION
- ②
 - TEMP. CYCLING: NONE
- ③
 - CONDUCTIVE COATING OF SOLITHANE FORM #6 + 5% BY WT. CARBON BLACK AND BRASS TAB ADDED TO MOLDED SURFACE.
- ④
 - USED 7.6 CU. CM. OF SOLITHANE FORM #6 TO BOND CENTER OF MOLDED SURFACE TO ALUMINUM CYLINDER

MFGR. DATE: JULY 19, 1976

STATUS:

SAMPLE #7, SOLITHANE, FORMULATION 2

**Pinch-off cap, 7.6 cc fill #6, #6 conductive coating,
no temperature cycling done.**

As far as is known: PERFECT Condition

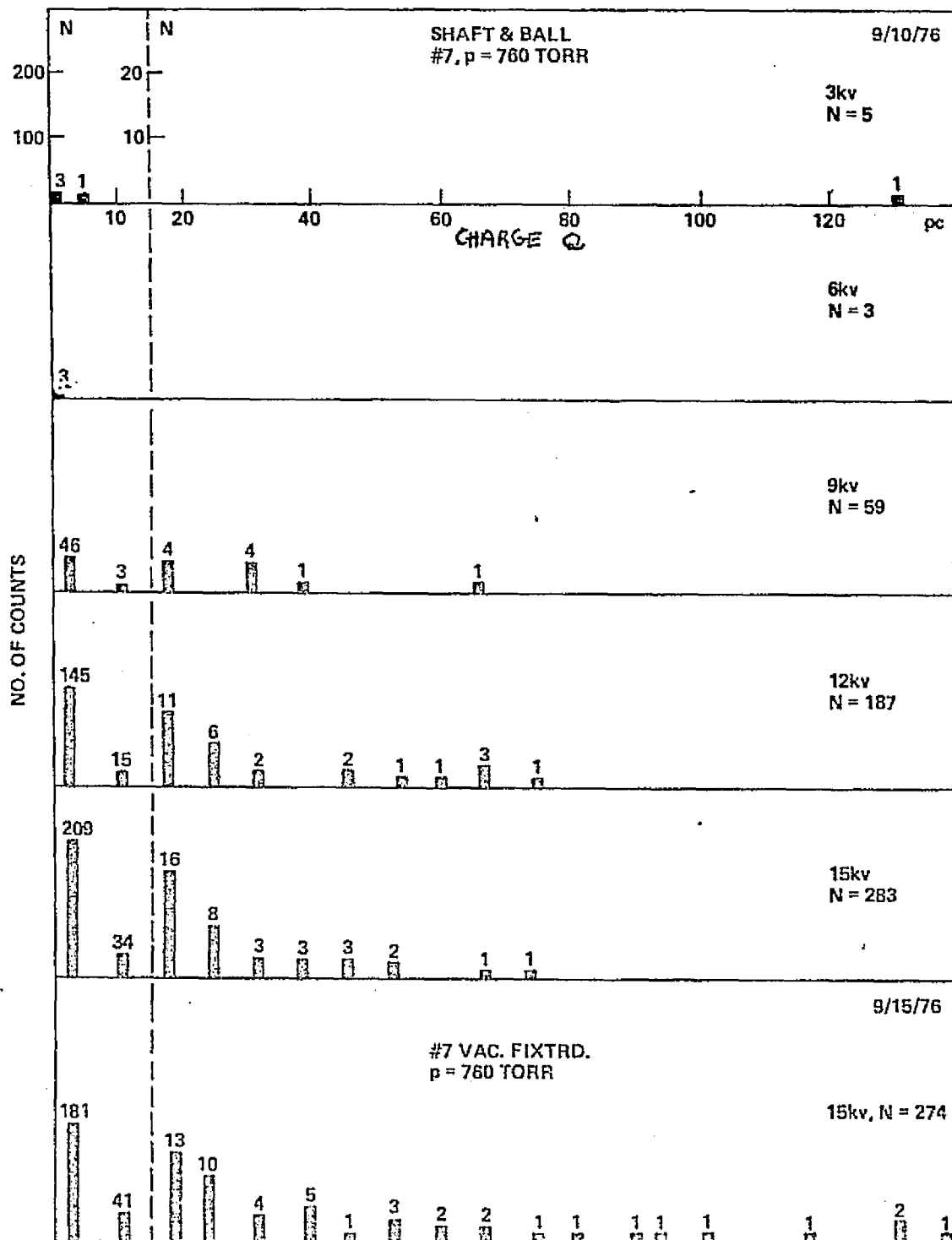


Figure 17a.

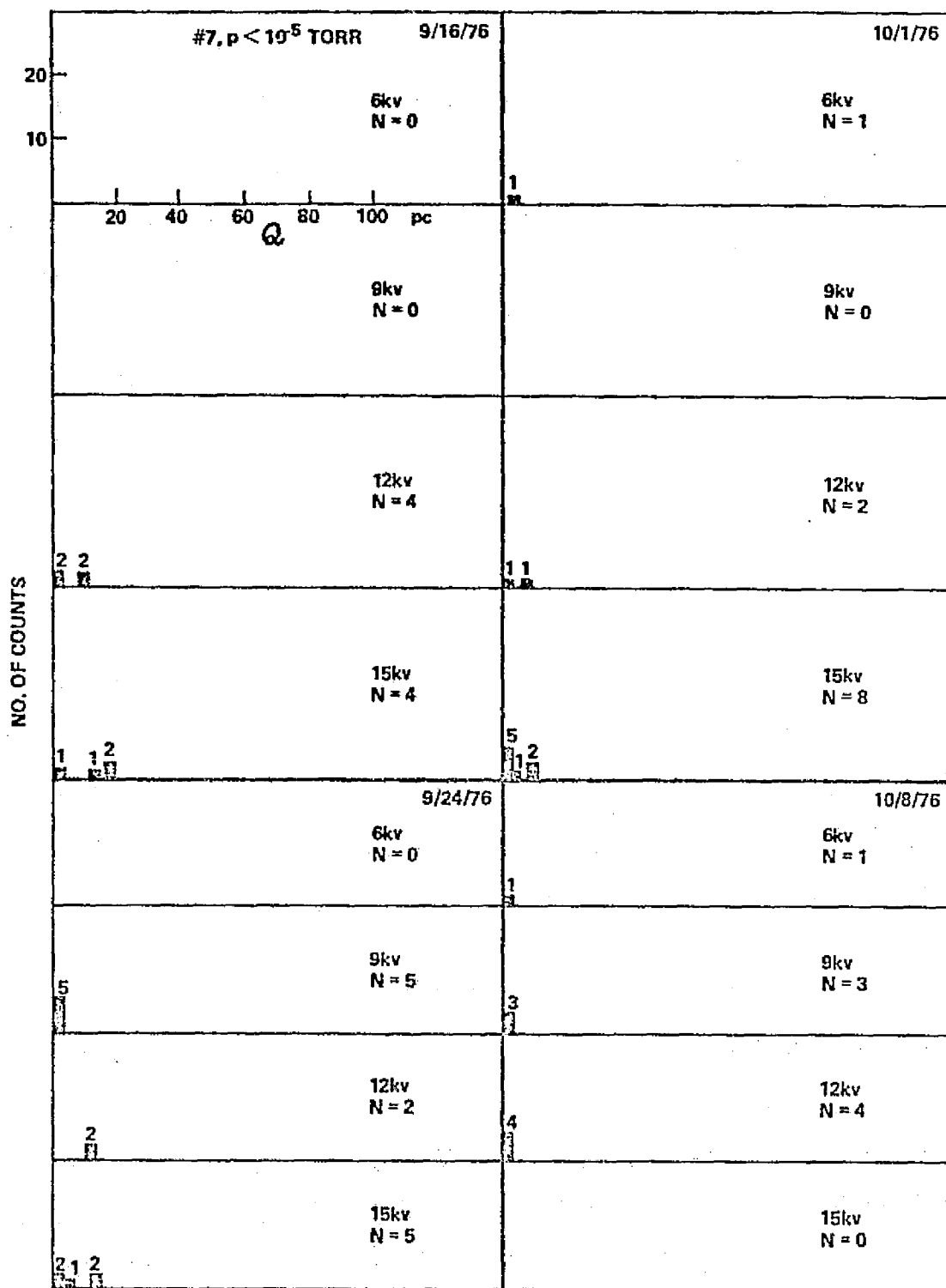


Figure 17b.

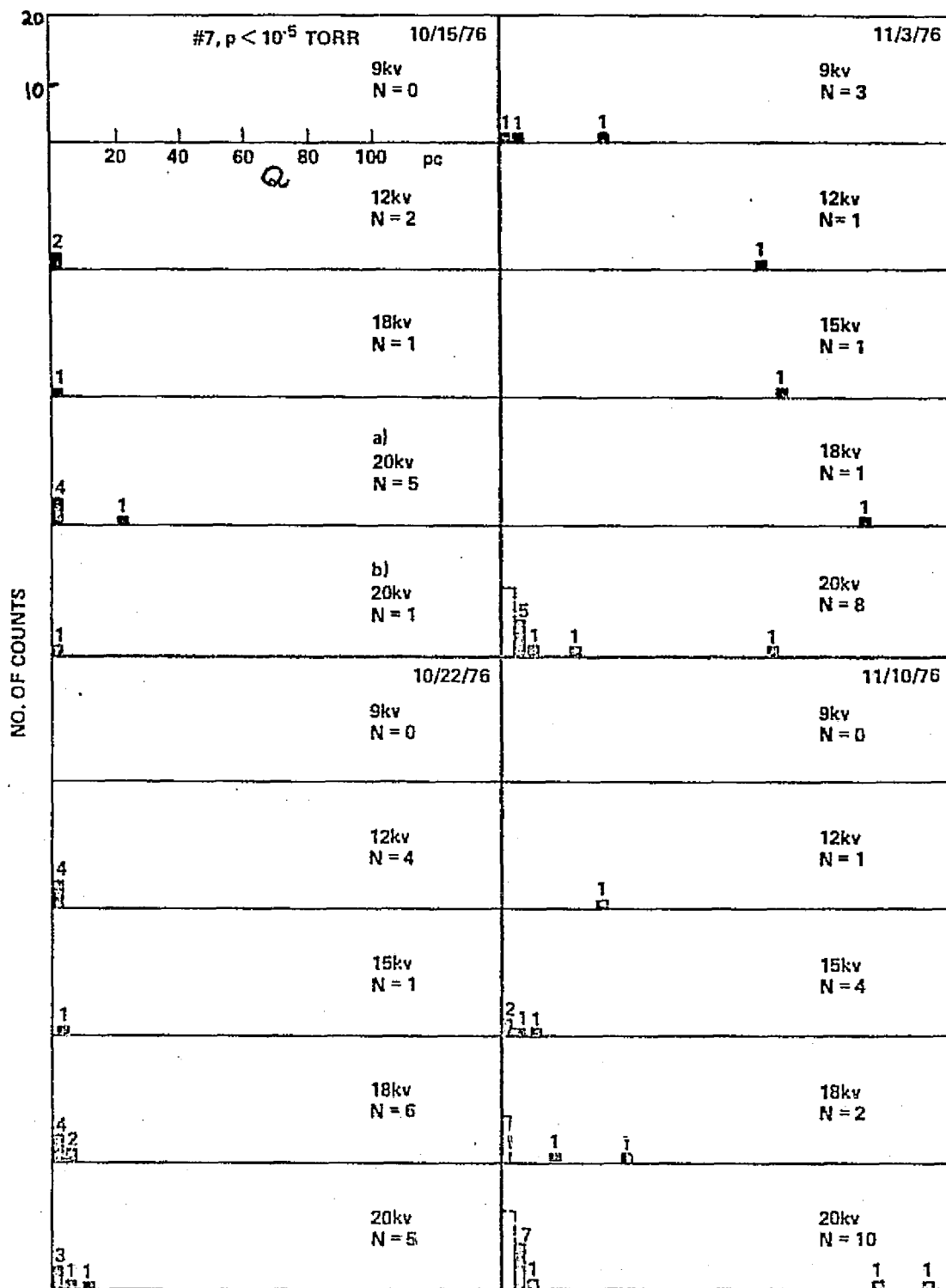


Figure 17c.

Figure 17d.

[illegible]

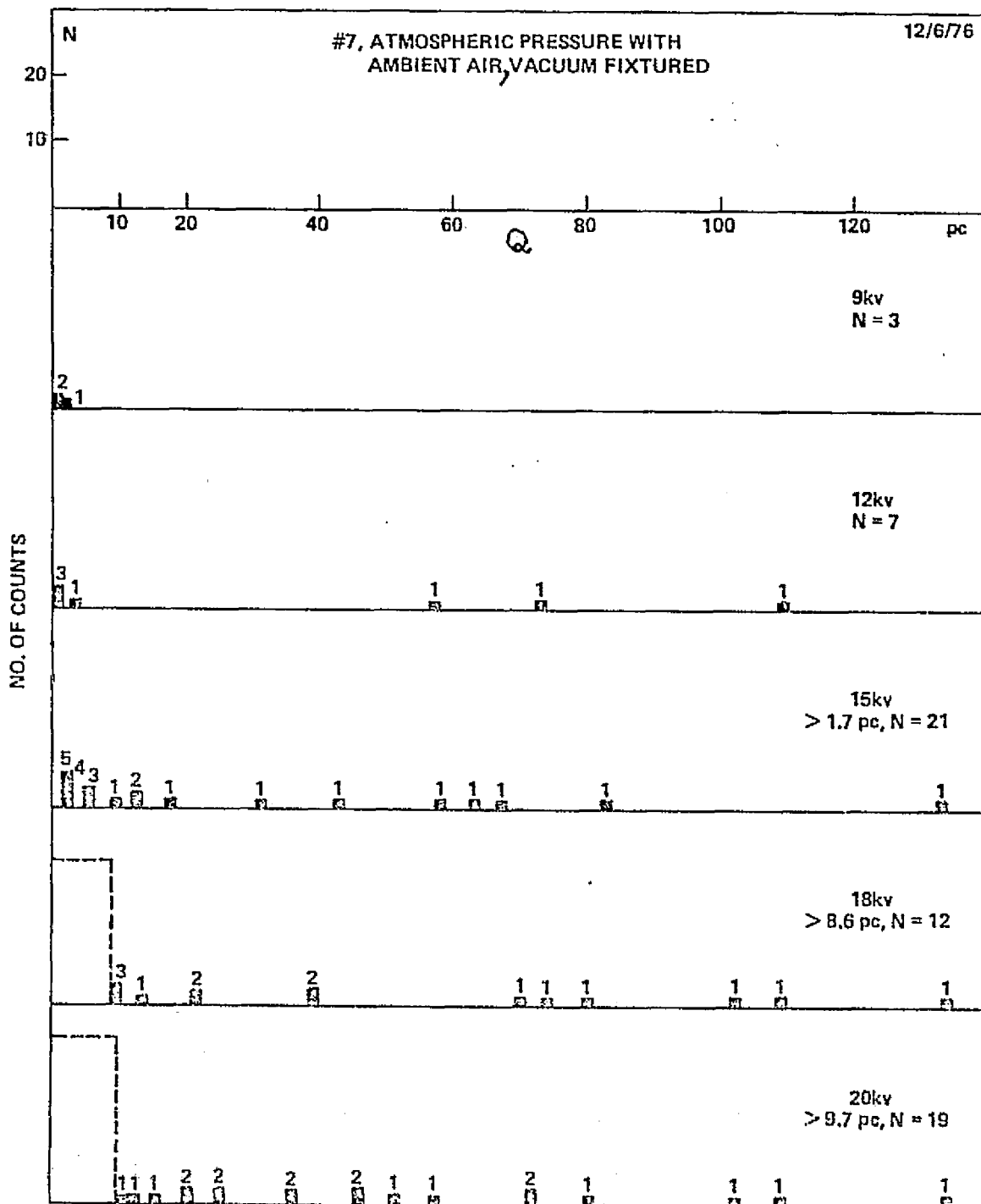


Figure 17e.

SAMPLE #7

This exhibits a large number of counts before the Life test. For the Shaft and Ball test taken in the Biddle enclosure there are 275 pulses at 15 kv, and when the unit is vacuum fixtured about a dozen counts move to much higher energies. After 1 week in high vacuum there remain less than 10 counts at 15 kv, low energy ones at that. This state of affairs continues for 4 weeks. Then P.D. testing (but not steadily applied voltage) is taken to 20 kv. In the seventh week 1 or 2 high energy counts, between 80 and 130 picocoulombs appear, which stay with the sample pretty consistently from then on; also there are 1 or 2 counts at 30-60 pc. In the 10th week the number of counts at low energy increases. Bringing the sample back to atmospheric pressure, still vacuum fixtured on 12/6/76 shows much fewer counts than 14 weeks previously, but still spread from 2 pc all the way to 135 pc. This cleaning up by vacuum has been observed by the writer in other P.D. work. Perhaps an explanation might be that while sitting around in ordinary air a sample adsorbs a great deal of water vapor on the surface which comes and goes as charged entities. After thorough outgasing in vacuum and re-exposure to air a monolayer of water vapor is immediately re-adsorbed of course, but the loosely bound excess of water vapor takes time to redeposit, and so the number of small pulses is greatly reduced, by a factor of 10 here. Note that the number of pulses above 30 pc is only diminished by a factor of 4.

This unit was run again after being in air for 2 weeks. The counts at 15 kv had already increased to about 60 and reevacuation immediately gave only a few counts again.

Another oft-to-be-observed effect is illustrated by this sample on the 10/8/76 test, for instance. At 15 kv there are fewer counts than at 9 kv or 12 kv. It must be reiterated that the repetition rate of D.C. Partial Discharge pulses in an internal void is a function of the bulk conductivity which re-charges the discharged void. The longer the high voltage has been applied, the more charge carriers have been trapped at shallow and deep traps in a good insulating material. Hence it is conceivable that sometimes there are fewer D.C. pulses at higher voltages in this series of measurements than at lower. Another possibility might also be space charge effects.

On a given test date the rate of rise was meticulously kept the same for all samples, that is, begin at 3 kv, acquire data for 200 seconds, record and raise to 6 kv in 100 seconds, acquire data there for 200 seconds, record and raise to the next level of 9 kv in 100 seconds and so on. Of course, later on in

the experiment one began at 9 kv and went on to 12, 15, 18, 20 kv, so the earlier and later rates of rise and time sequences are not really comparable.

The "dotted" blocks in the histograms from 1 pc to 10 pc indicate that the Biddle system was noisy there. Hence no data could be recorded in that region.

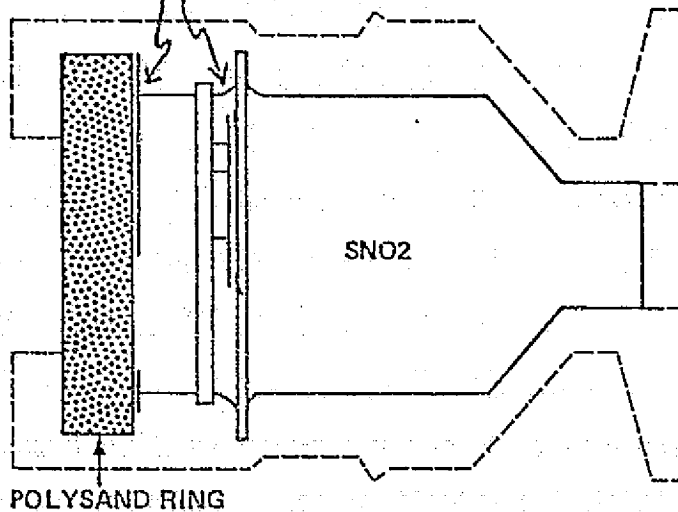
SAMPLE #2, SOLITHANE, FORMULATION 2

Pinch-off cap, 7.6 cc fill #6, #6 conductive coating, four temperature cycles.

Condition: In convoluted area there is no primer. In worst convoluted area there are small cracks and some bad adhesion. There is a large area of bad adhesion at the polysand.

SNO2

**IN VICINITY OF POLYSAND CONVOLUTED AREA
ON INSIDE SURFACE
— CRACK & DELAMINATION**



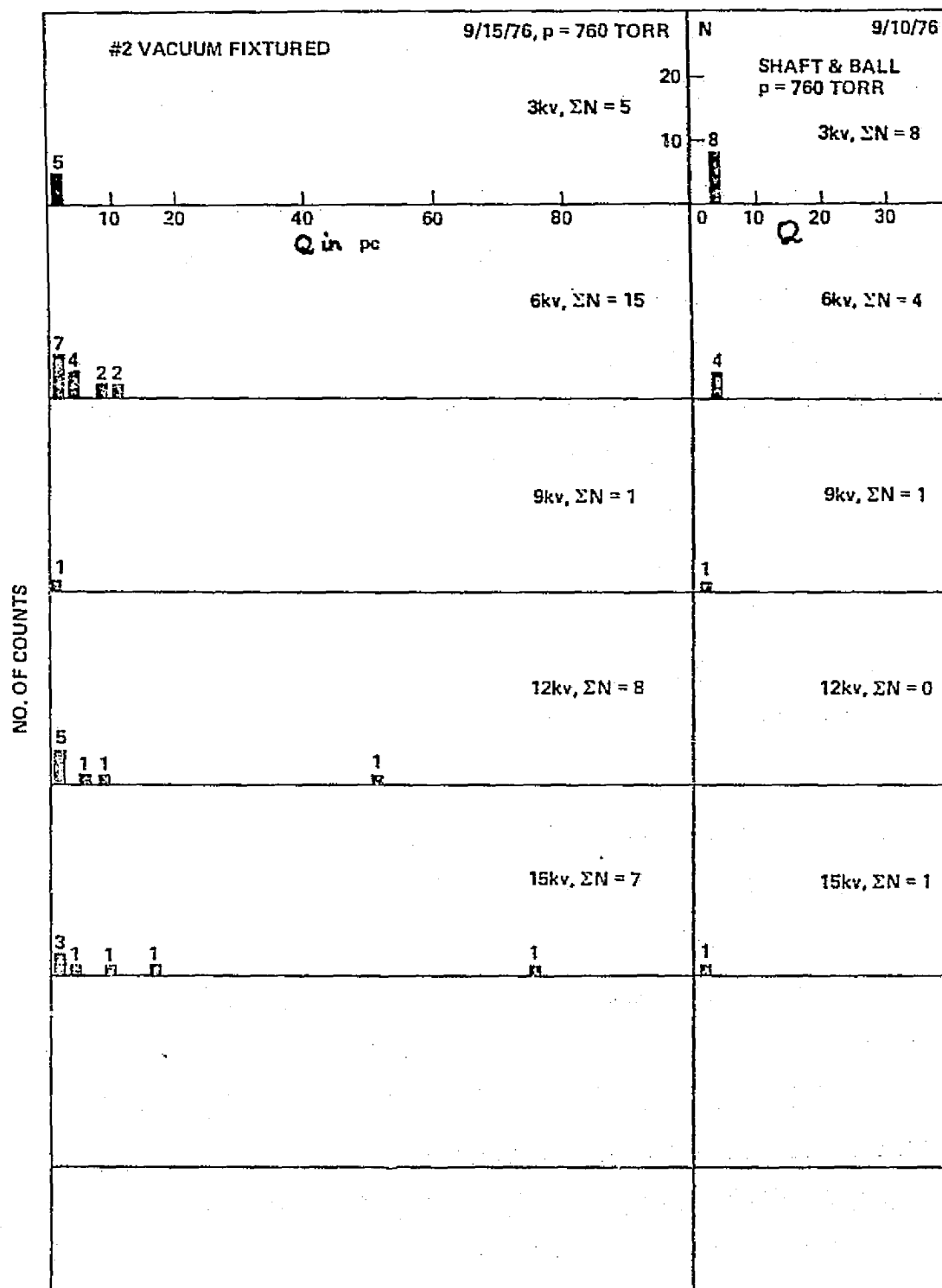


Figure 18a.

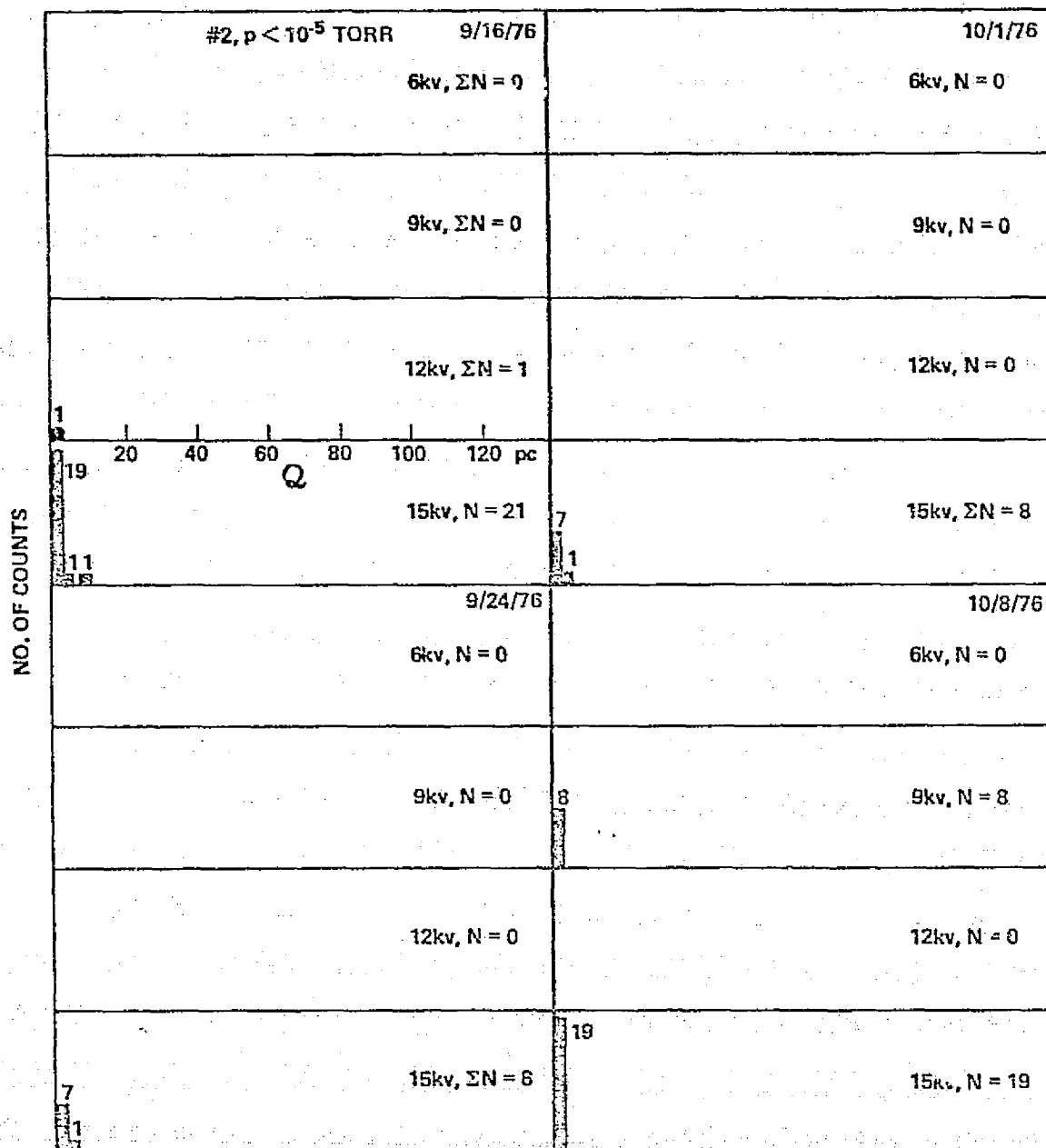


Figure 18b.

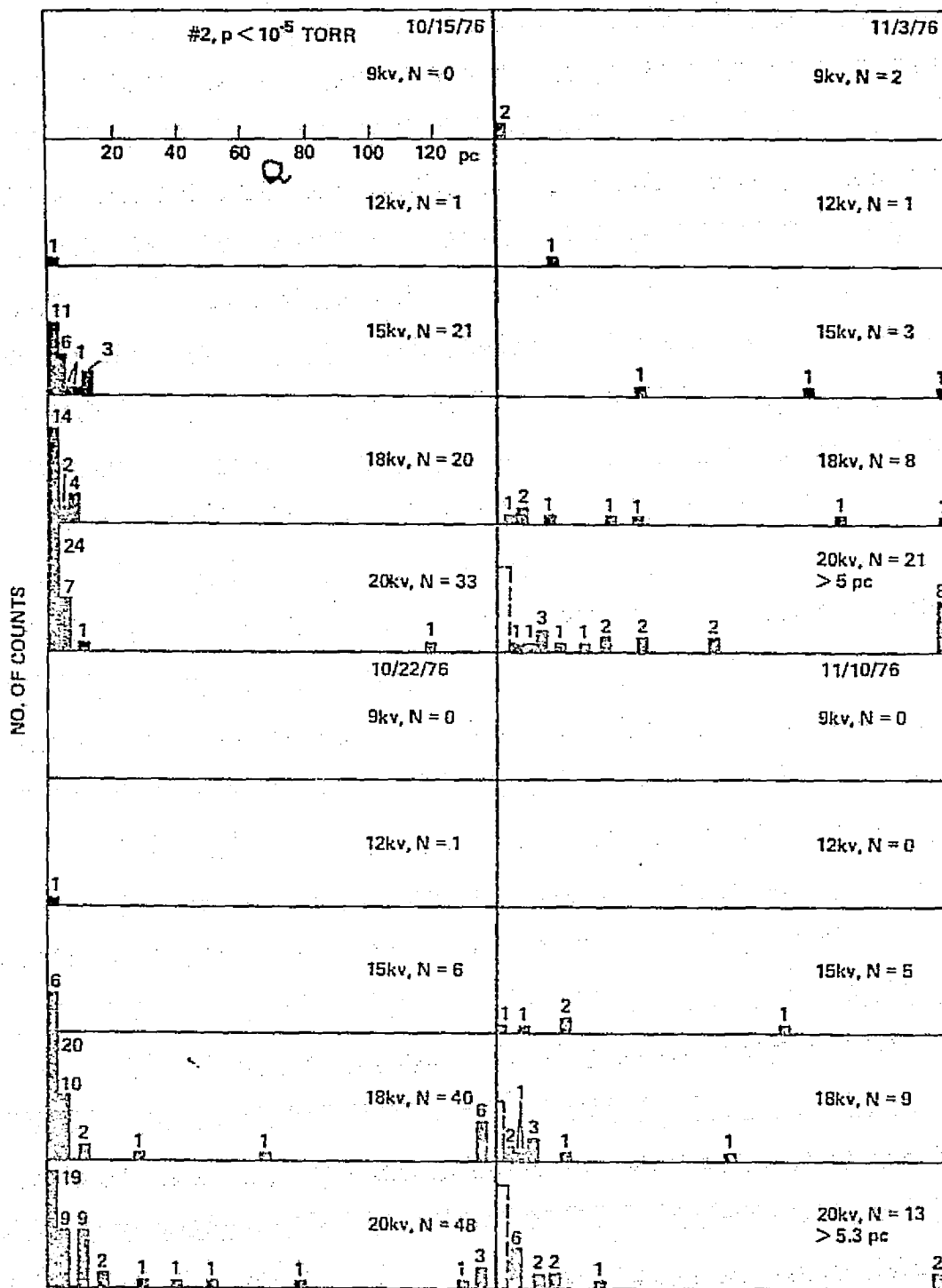


Figure 18c.

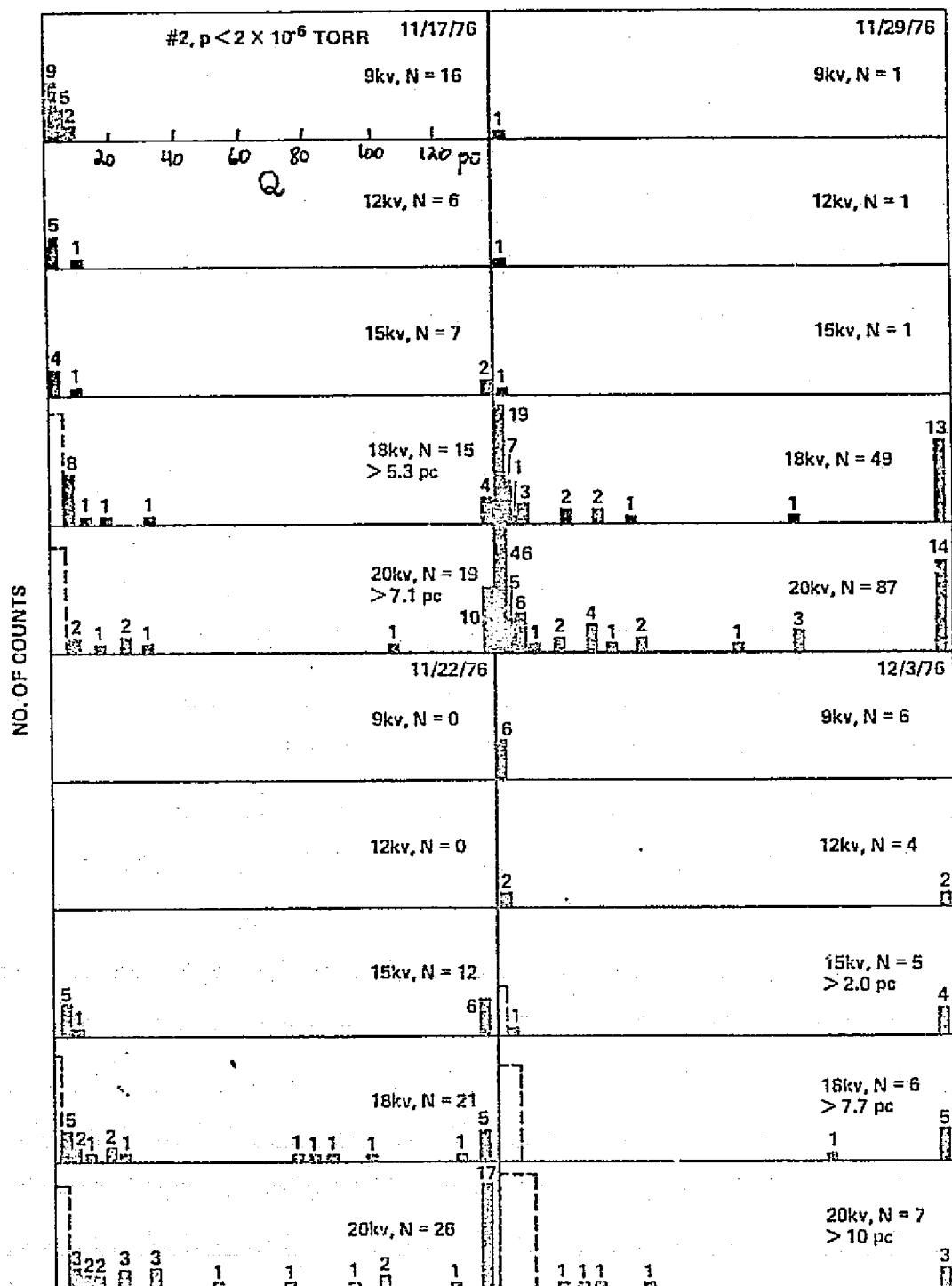


Figure 18d.

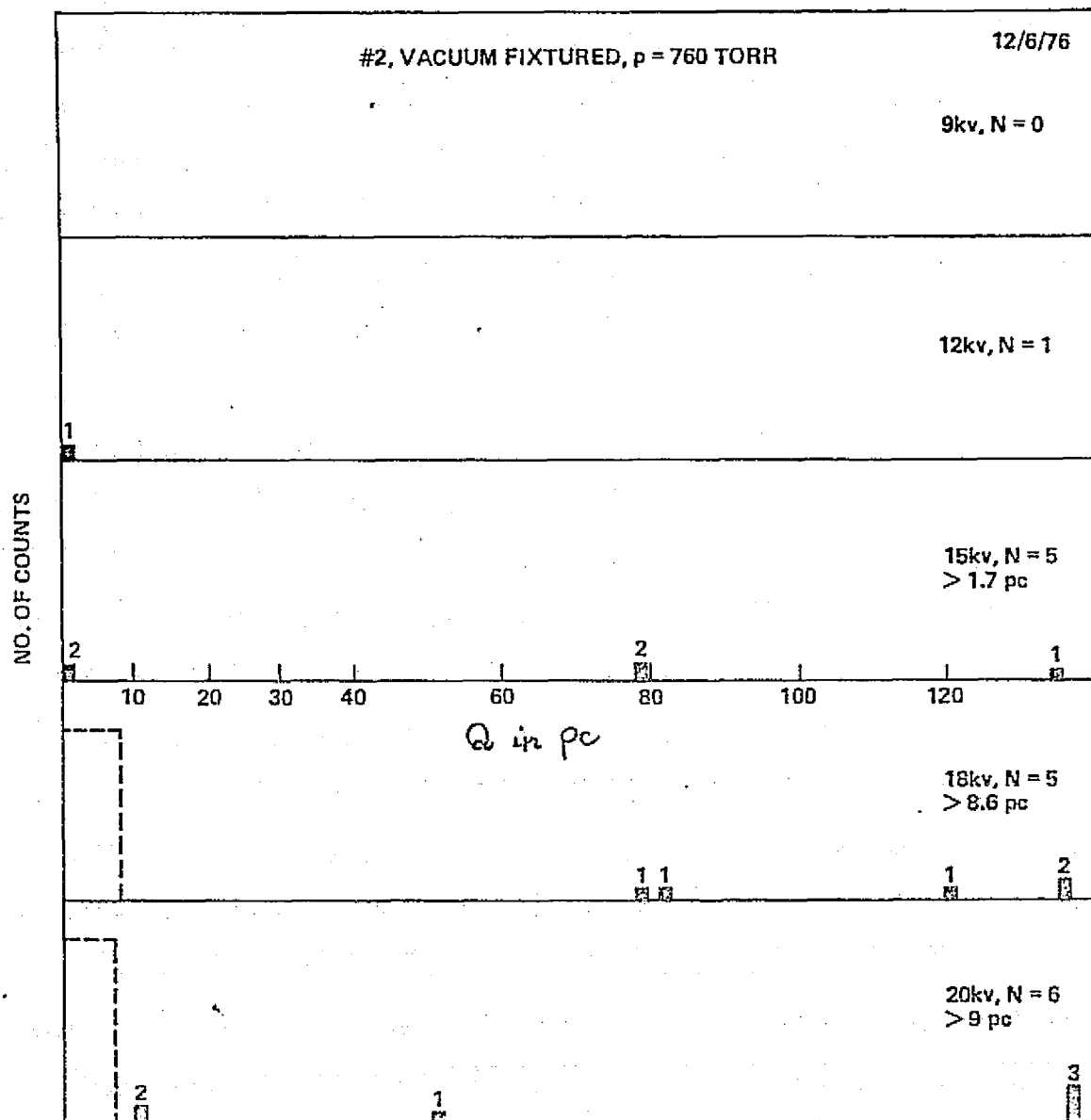


Figure 18e.

SAMPLE #2

This sample is also Solithane, formulation #2, but has delaminations by visual and X-ray inspection.

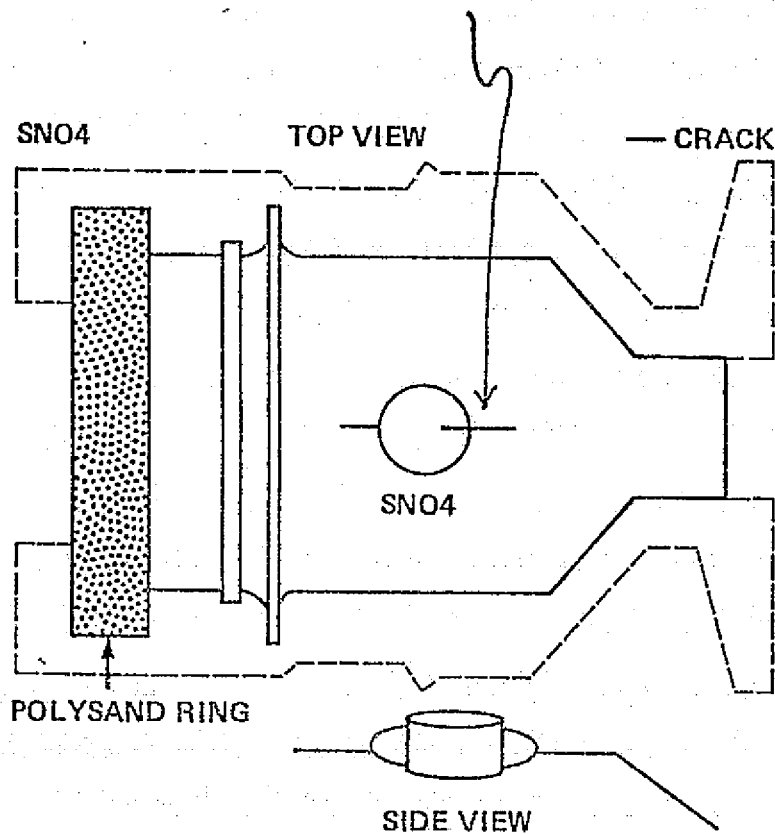
In air, before the Life test it has only 1 count at 15 kv, in the Biddle enclosure; there are 7 counts, one high energy, when vacuum-fixture. Note that there are more counts at lower voltages than at higher just as discussed with sample #7. During the first four weeks in vacuum there appear between 8 and 20 low energy counts at 15 kv. By the 6th week, after testing to 20 kv was done, there are more low energy counts and some high energy ones too. This is worst during the eleventh week with 87 counts at 20 kv, 14 of these at 135 pc. Then during the 12th week things suddenly improve with only 7 counts above 10 pc, 3 of them at 130 pc. There is not much increase in counts between the Before and After Life test at atmospheric pressure at 15 kv.

The sudden improvement during the 12th week can not easily be explained. The hypothesis can be advanced that diffusion of air out of the delaminated region first made things worse and then better as the pressure went through the Paschen minimum. Rather than relying on calculations that are uncertain for such a thick specimen of irregular geometry, the author would suggest that sample #2 be mounted back in high vacuum, with 15 kv applied continuously for 10 more weeks. It should then be tested for Partial Discharge again, both at high vacuum and at atmospheric pressure to see if further increase in count rate has occurred, which would indicate insulation damage.

SAMPLE #4, SOLITHANE, FORMULATION 2

Pinch-off cap, 7.6 cc fill #6, #6 conductive coating, three temperature cycles.

CONDITION: CRACK AT THE PINCH-OFF CAP.



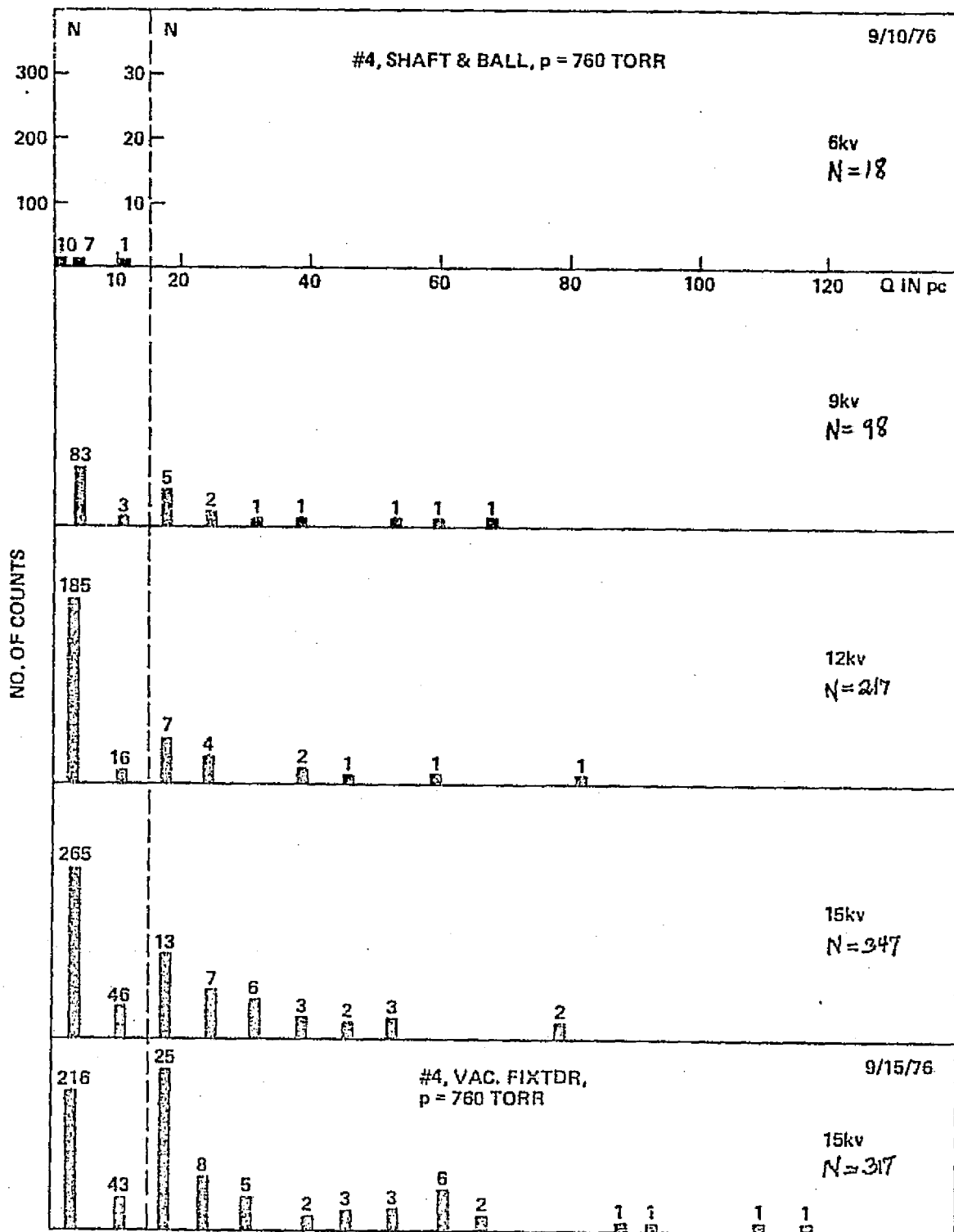


Figure 19a.

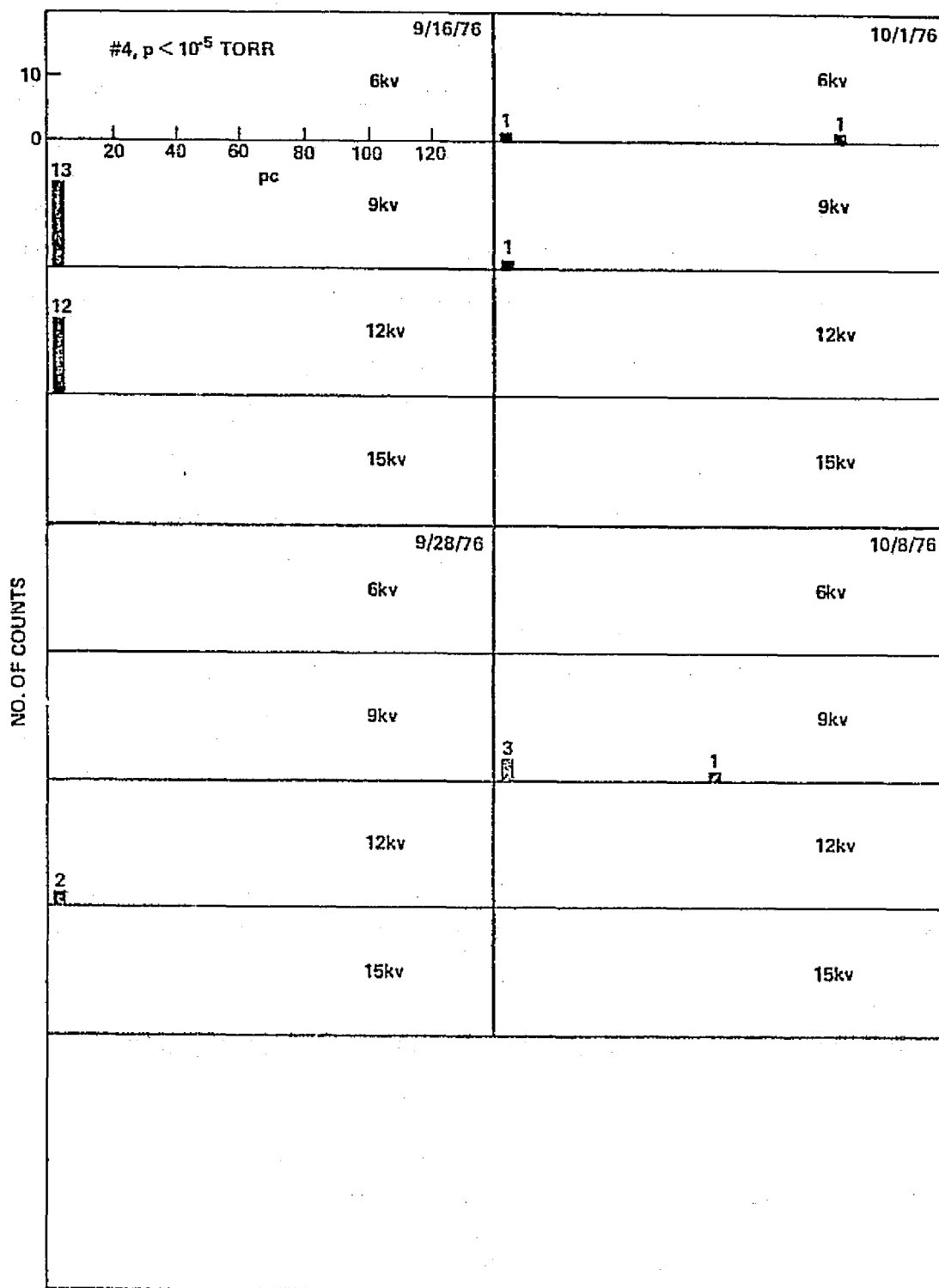


Figure 19b.

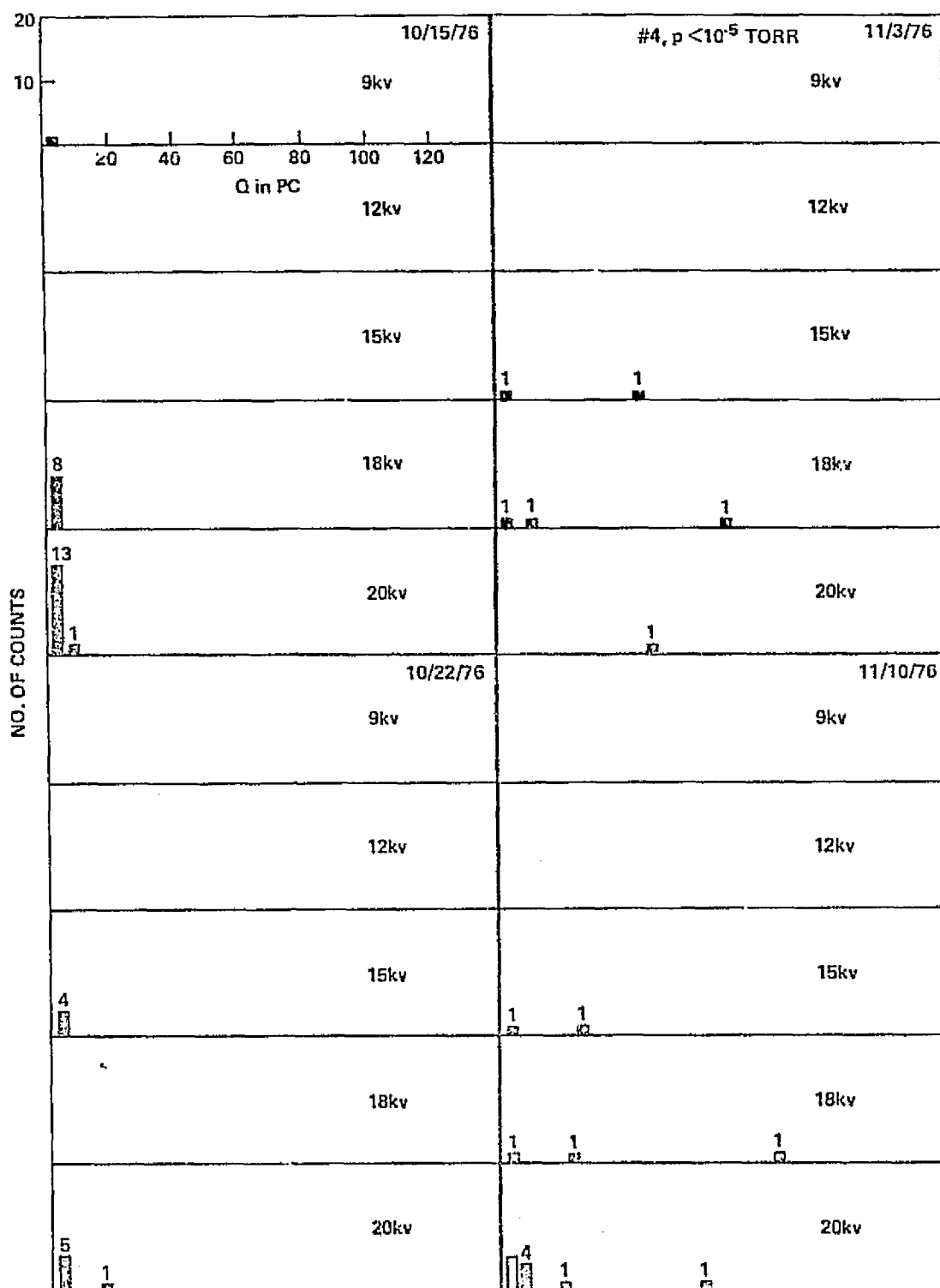


Figure 19c.

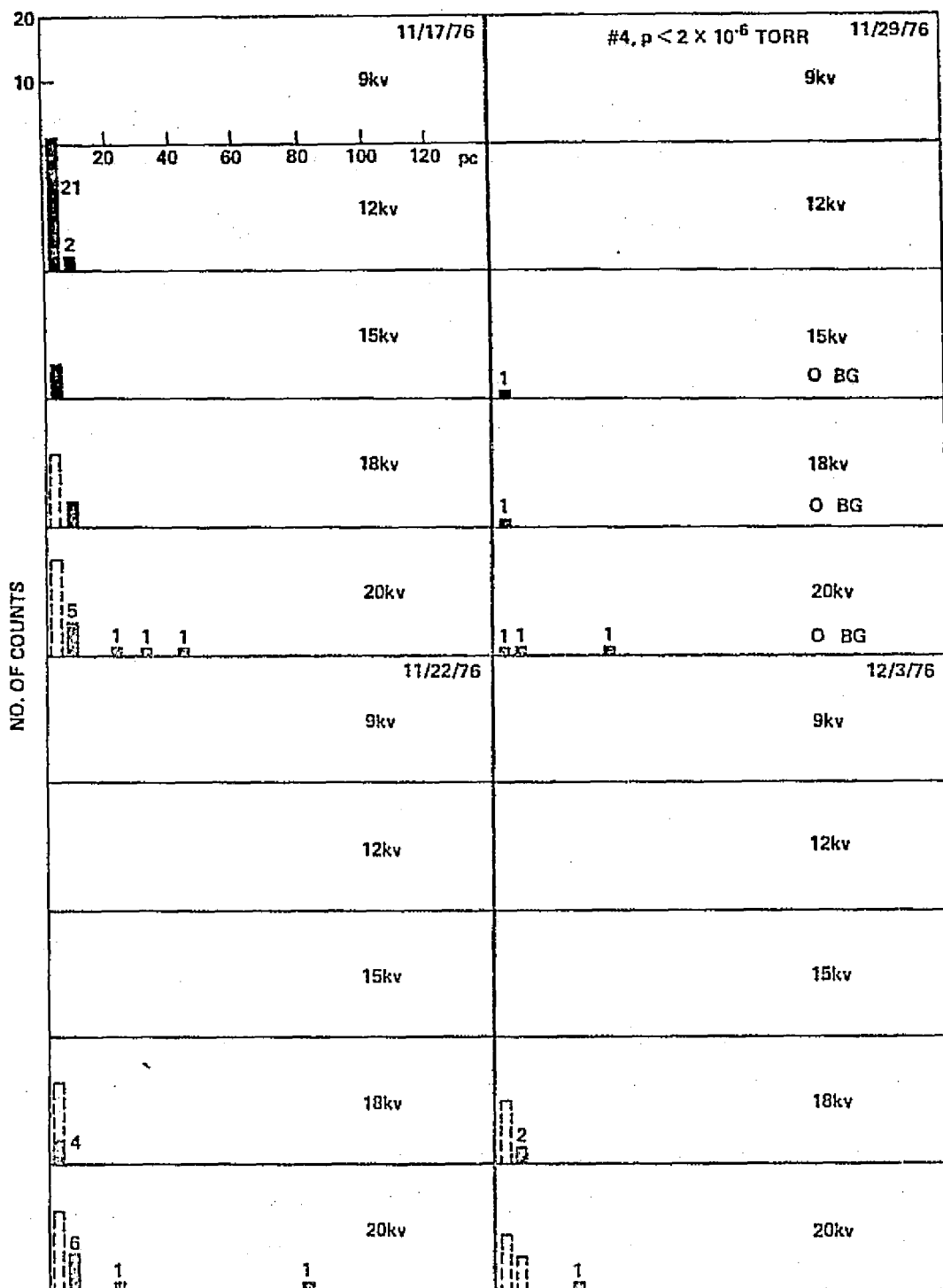


Figure 19d.

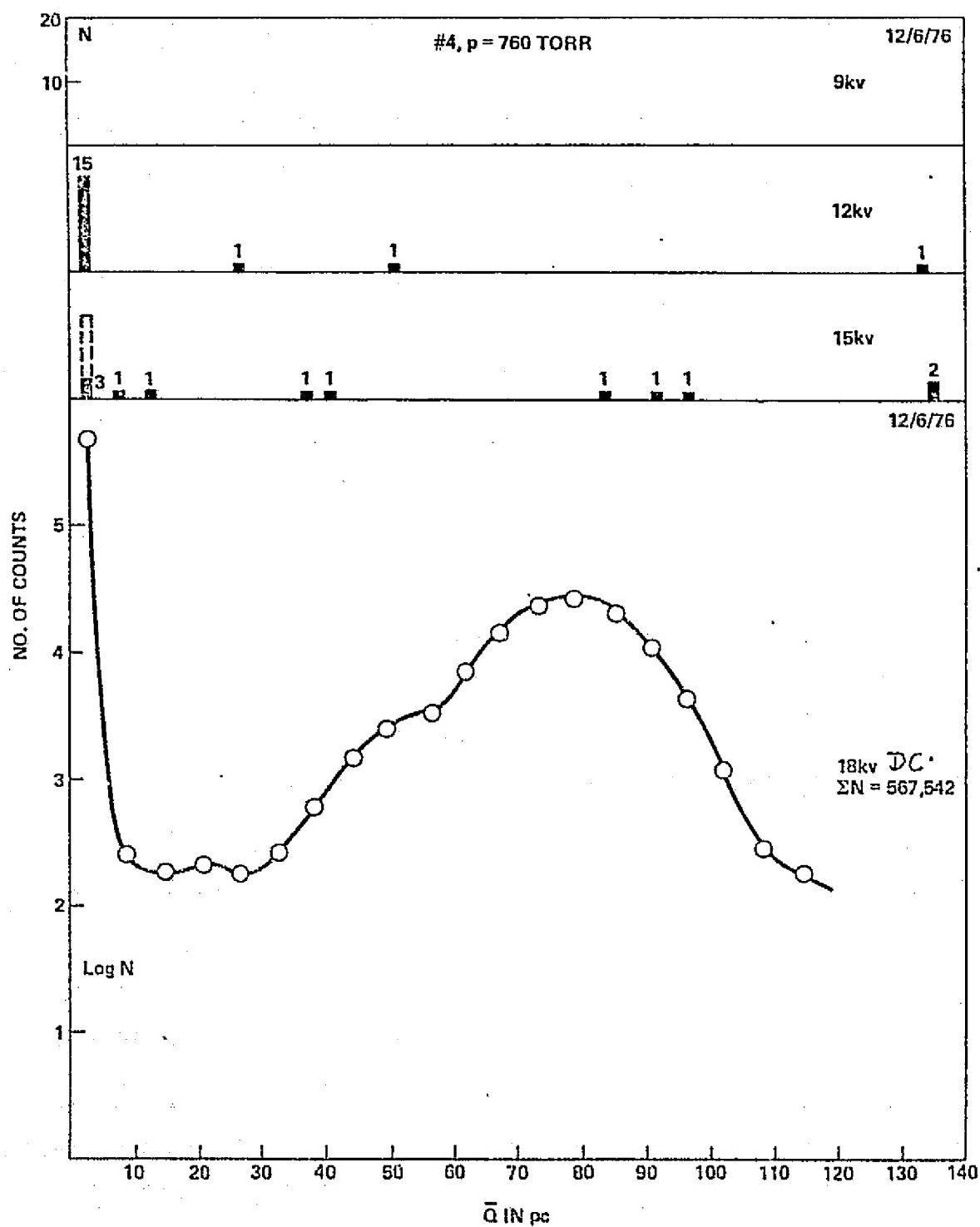


Figure 19e.

SAMPLE #4

It is Solithane, formulation 2 and has a crack at the pinch-off cap. Similar to #7, there are between 250 and 300 counts at atmospheric pressure. A dozen high energy counts are introduced by vacuum fixturing. Again, by the second week of high vacuum the counts have all but disappeared. So one can conclude that the earlier counts were due to surface effects. Tests up to 20 kv produce only one or two between 20 and 90 pc, even to the end of the 12th week.

Bringing the sample back to room pressure and testing to 15 kv shows only 12 counts. But then as the voltage is raised to 18 kv there is sudden onset of breakdown with 560,000 counts and no previous warning. This is thought to be due to surface-flashover across the end of the specimen from the central shell to the outer shell. The reasoning is as follows:

- 1) Reducing the voltage and starting over again permits one to repeat the quiet data at 9, 12, 15 kv. Bulk-breakdown would burn a permanent channel and would not permit this.
- 2) Placing the sample back in vacuum for two more weeks and then back to atmospheric pressure again permits repetition of the quiet data.
- 3) Visual concentration during repetition of 2) at atmospheric pressure, as the voltage is raised toward 18 kv permitted the experimenter to observe the flashover glow.
- 4) A test under transformer oil is planned to further verify that this is surface flash-over. In other words, it should be totally absent under oil.
- 5) Dissection, finally, is also planned.

So, discounting the surface flash-over, there was no evidence of notable deterioration during the Life test, even with the small crack at the pinch-off cap.

SAMPLE #9, EN-11 CONATHANE

Pinch-off cap, 7.6 cc fill #6, #6 conductive coating, no temperature cycling done.

CONDITION: No statement.

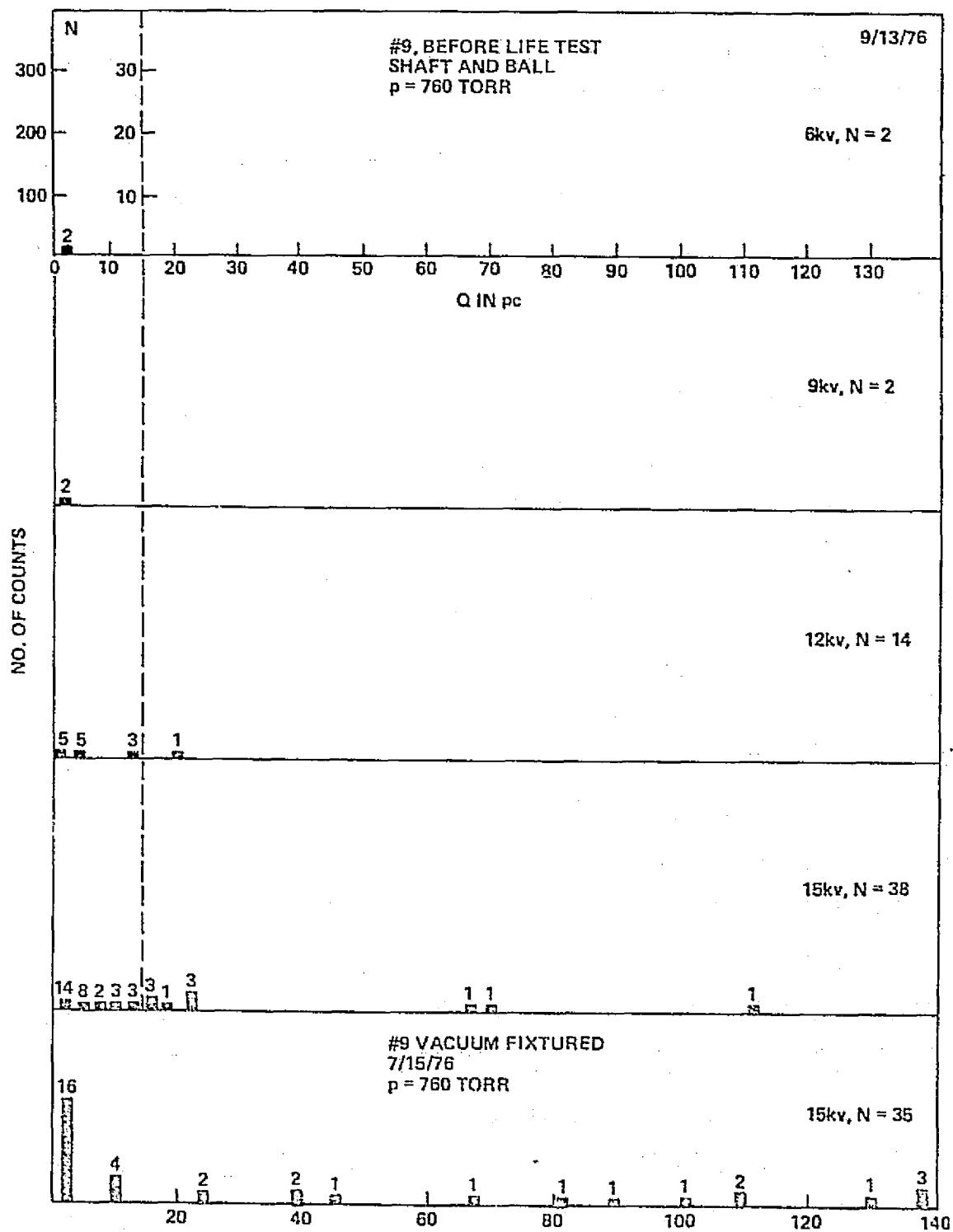


Figure 20a.

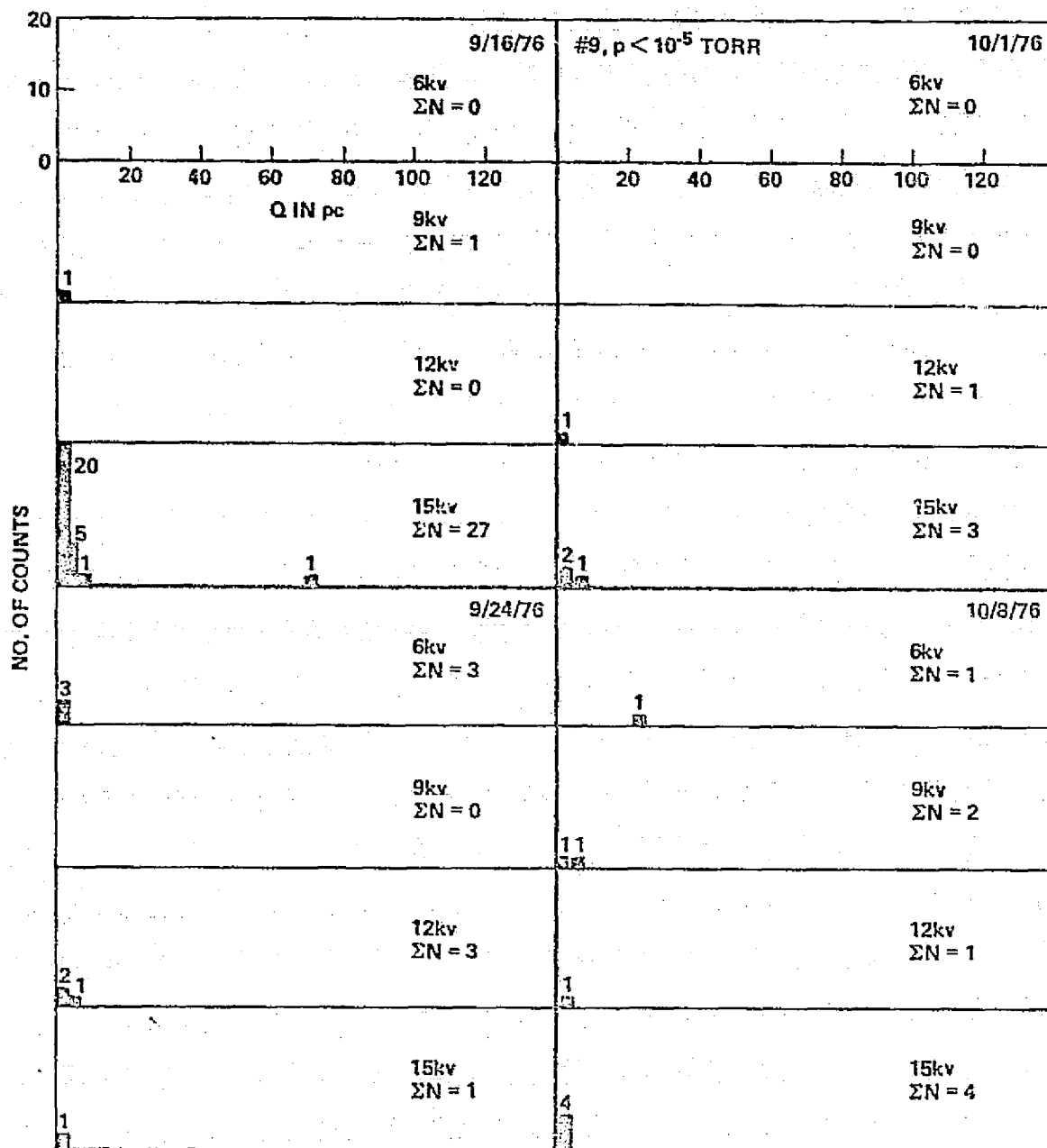


Figure 20b.

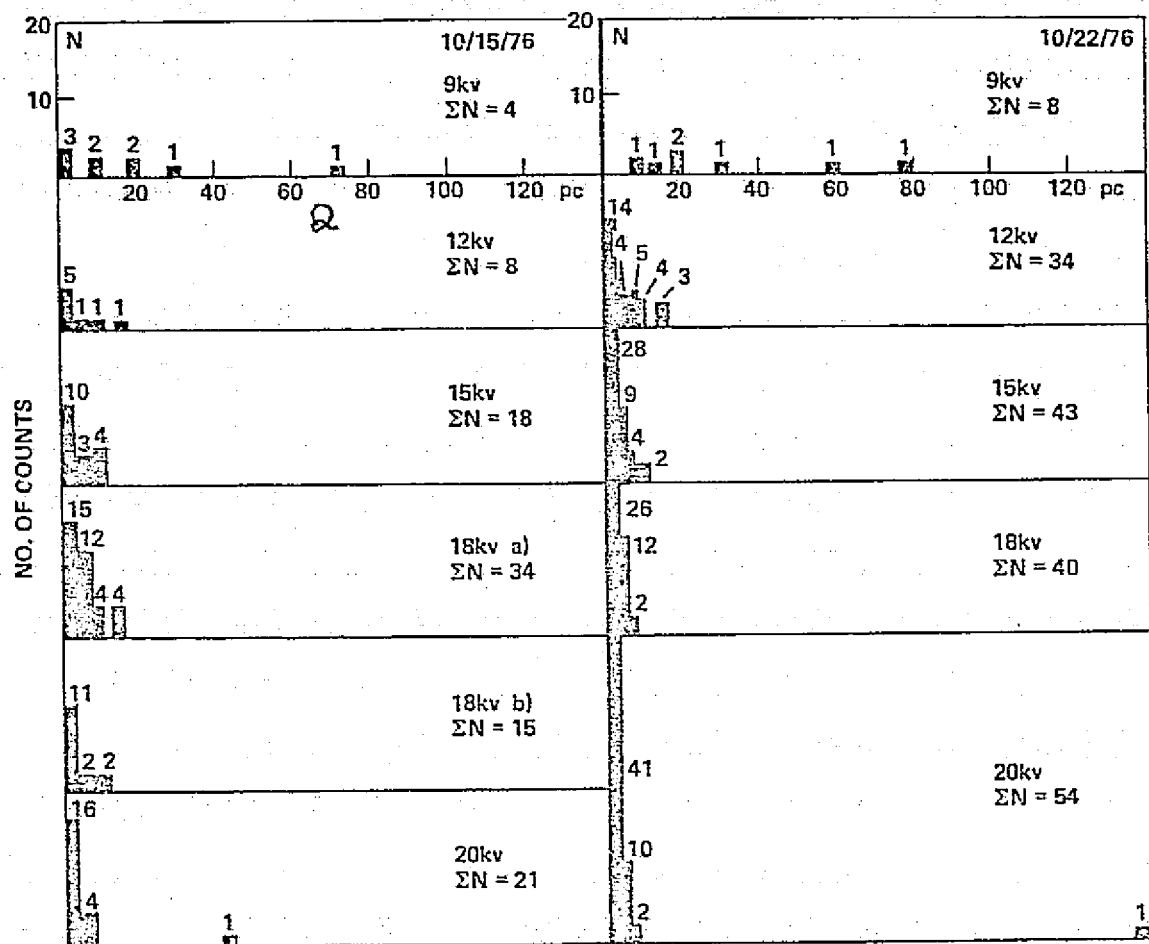


Figure 20c.

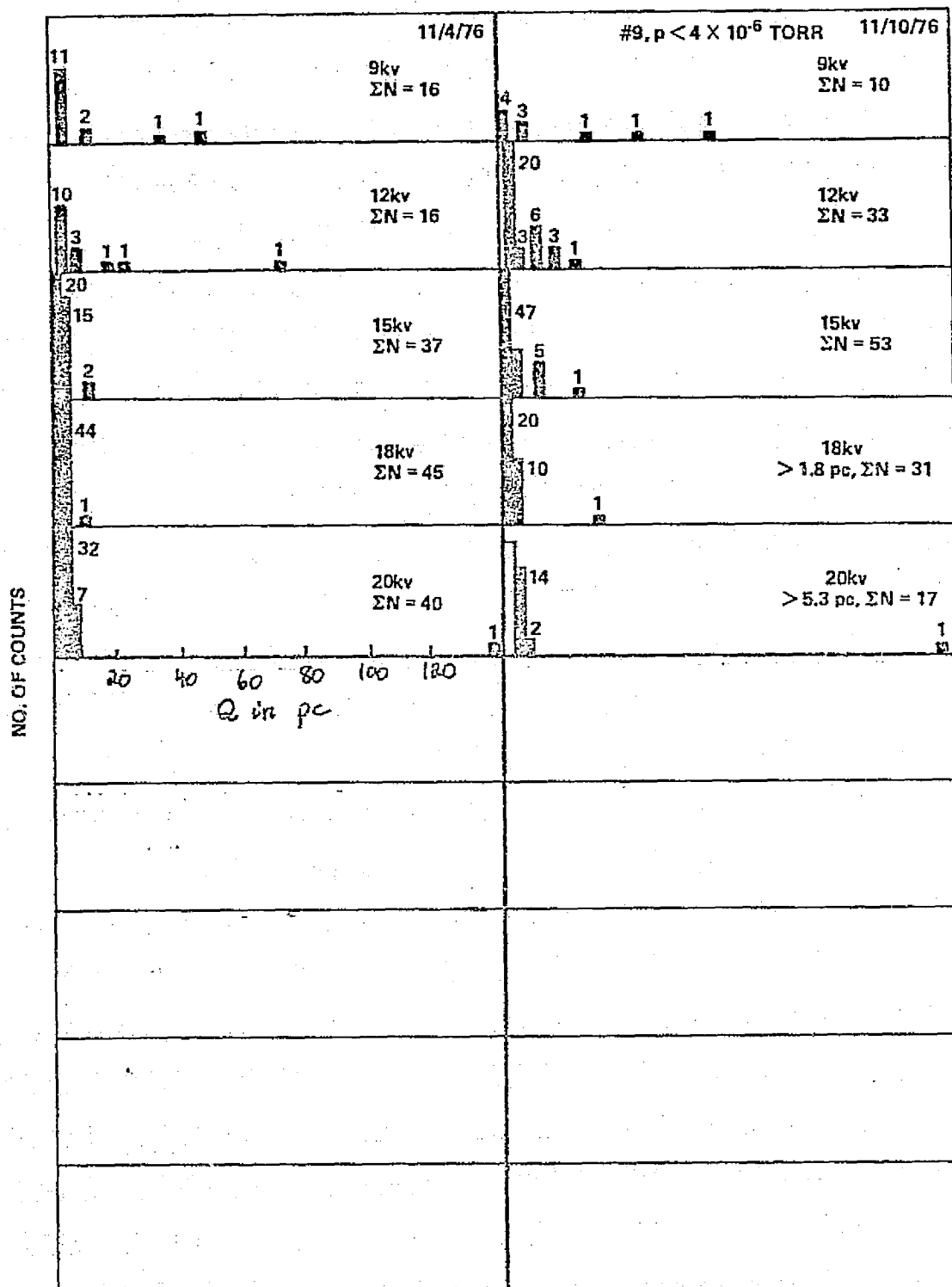


Figure 20d.

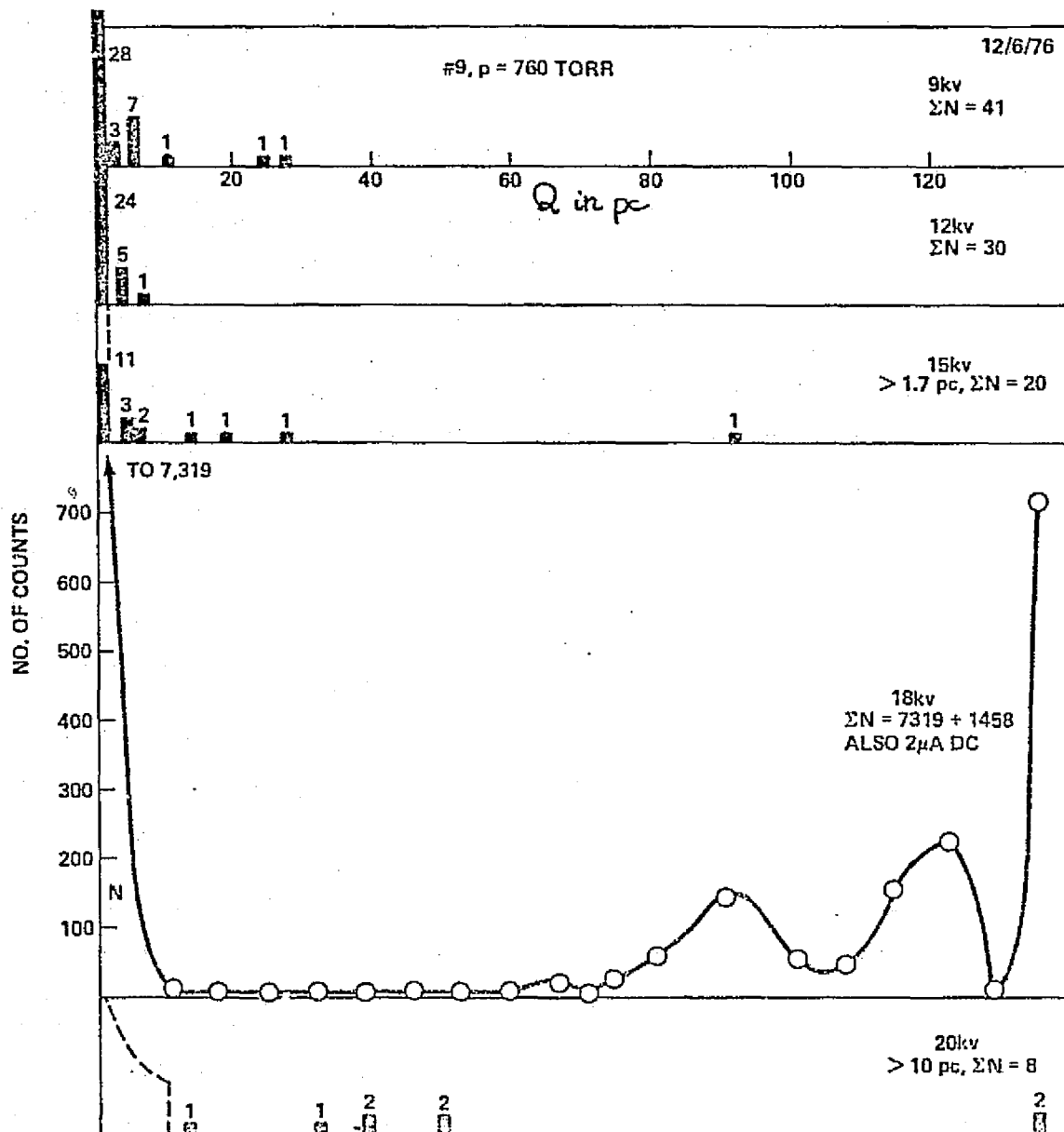


Figure 20f.

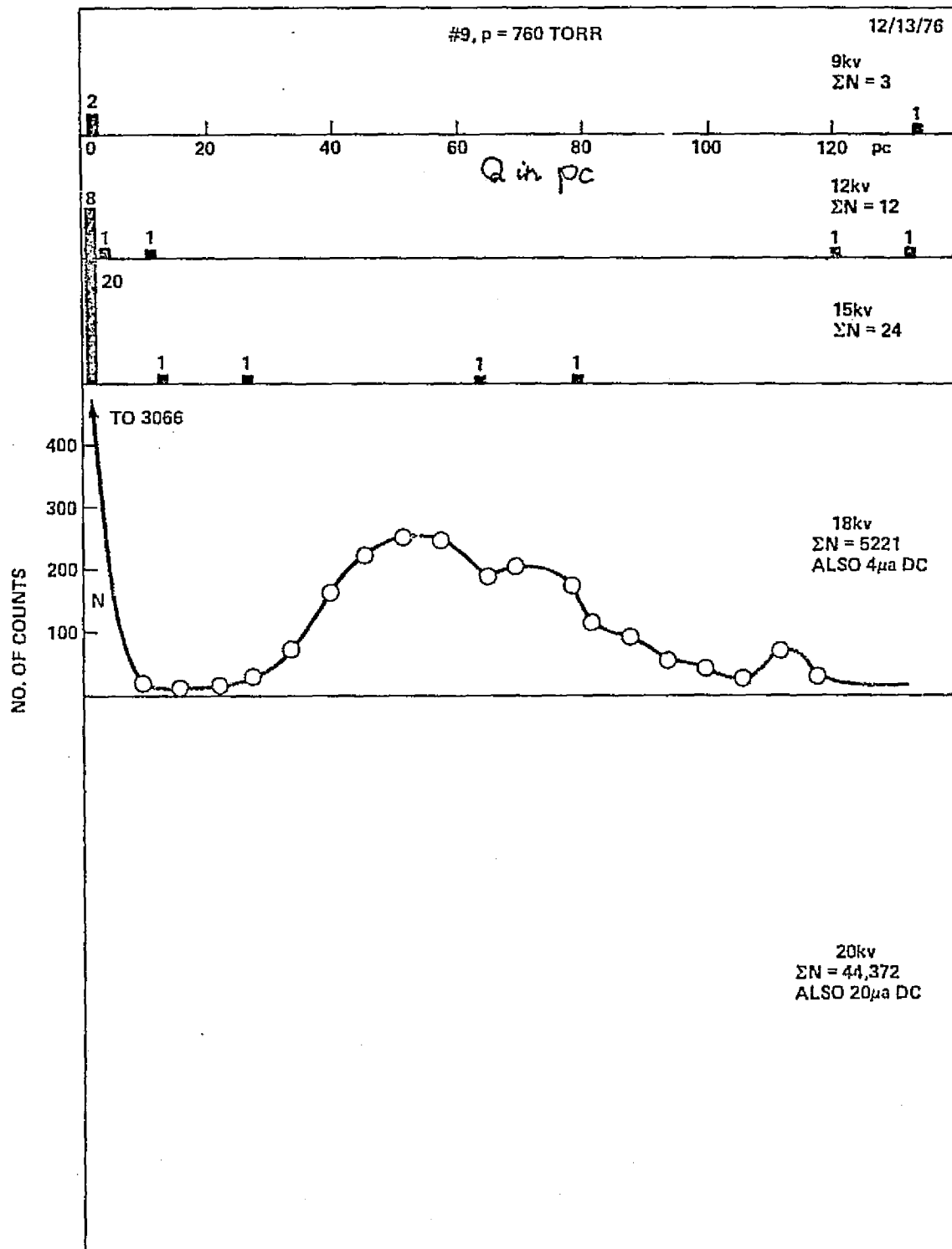


Figure 20g.

SAMPLE #9

This is Conathane EN-11. There is no statement as to its internal condition.

It behaves very similar to sample #4 and #2. The "Before" Life test in the Biddle enclosure shows 38 counts, vacuum fixturing causing 10 of these to move to higher energies all the way to 140 pc (or higher; the amplifier saturates at 135 pc, so the last 3 counts are probably higher). After two weeks in vacuum the counts are down to 2 or 3. They increase during the 5th week into the 40's, some high energy ones being pretty persistent. Strangely, the count rate diminishes in the 12th week, again.

Back at atmospheric pressure, the count rate is much less than during the "Before" test, at 15 kv. But again, just as with the Solithane sample #4 at 18 kv there is sudden surface flashover. It is intermittent and self-extinguishes, and the whole series of data from 6 kv on up could be repeated several times. The entire behavior at atmospheric pressure is thought to be due to the surface geometry of the test sample rather than a materials problem of Solithane versus Conathane.

The increase of small pc counts while in vacuum is something to worry about, and this sample should be placed in vacuum for another 10 weeks, and then retested in the Biddle system both in vacuum and at atmospheric pressure.

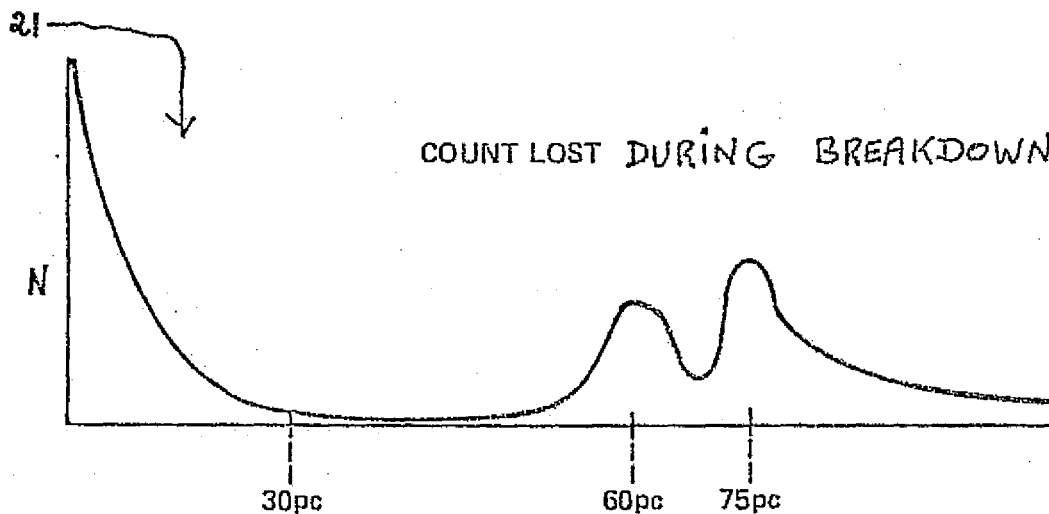
Finally, the sample should be dissected to further verify that surface flash-over is the only explanation for the breakdown at 18 kv when back at atmospheric pressure.

POINT TO PLANE SAMPLE

Sylgard 184. Spacing of 0.007" from point to plane. Radius of point 0.015".
Solder coat on beryllium-copper. $P = 76 \text{ cm Hg}$.

This sample had a obvious region of poor adhesion on the plane.

Applied volts KVDC	Total counts	Charge level pc	Counts	Charge level pc	Counts
3	15	1.4-28.6	14	65.2	1
6	137	1.3-31.3	135	30 - 50	2
9	257	1.0-24.0	245	26.8- 68.3	12
12	404	1.0-25.5	387	27.7- 55.9	17
15	893	1.0-27.8	873	29.3- 74.3	20
15	644	1.0-33.0	624	34.5- 71.9	18
15	583	1.0-29.9	559	31.6- 60.8	23
18	719	1.0-46.2	436	46.4-113.2	283
18	680	1.0-25.0	360	27.2- 98.7	320
18	652	1.0-34.0	334	34.2-100.4	318



$P = 760 \text{ TORR.}$

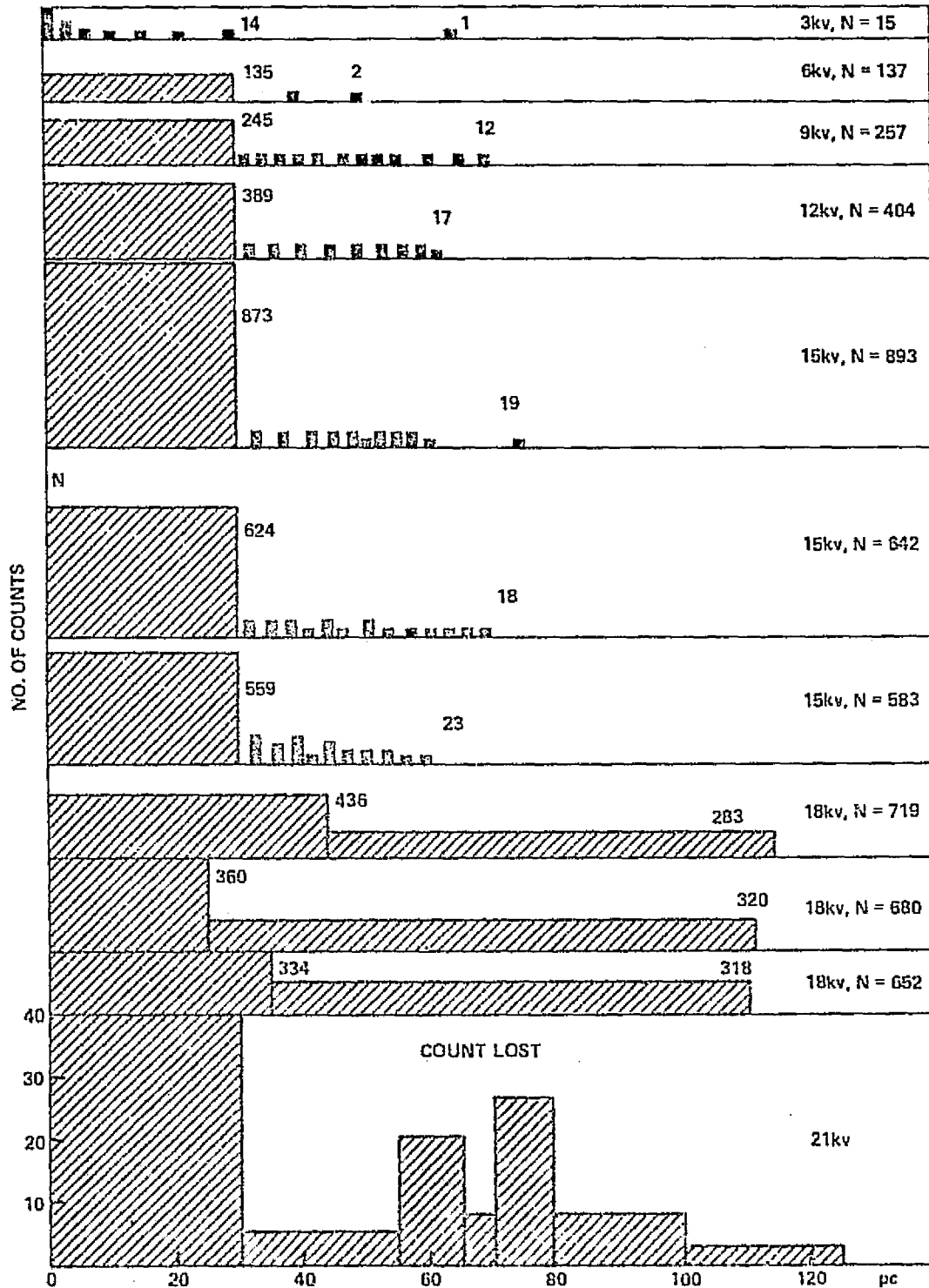


Figure 21

POINT TO PLANE SAMPLE

Sylgard 184 Silicone rubber, 0.007" thick between point to plane. Radius of point 0.015".

For contrast with surface flash-over, data taken on an entirely different configuration is presented here. The histograms as bulk breakdown is approached show clear signs of impending trouble.

Unfortunately, during this data sequence photographs of the Multichannel Analyzer read-outs were not taken. Instead, block data was recorded: so many counts up to 30 pc of charge content, and so many counts 30 pc to 135 pc. The actual distributions were, of course, not in square blocks, but fell off from a maximum at 1 pc.

Note the following:

Up to and including the 15 kv data runs there are only about 20 counts above 30 pc charge content to hundreds of counts below 30 pc. During the three successive data acquisitions at 15 kv the total number of counts decreased, the number of small energy counts decreased, from 873 to 559, but the number of higher energy counts increased from 19 to 23.

Then at 18 kv: a) the total number of counts on the first run was less than at 15 kv; b) the total number of counts still decreased with time; c) the small energy counts decreased with time from 436 to 334; d) the higher energy counts increased from 283 to 318; e) the proportion of high energy counts to low energy counts was far greater at 18 kv than at 15 kv and kept growing as time went on. In fact, a second peak kept growing at the intermediate energy range of 60 to 80 pc.

When the voltage was raised to 21 kv that second peak split into two distinct peaks at about 60 kv and 80 kv; before the sampling time of 200 seconds was up, the specimen broke down catastrophically and the detailed data was lost in the onslaught of counts.

Experiments are now in progress to repeat this data. In the attempt to "slow" down the sequence of events a new sample was overdesigned. That is, the spacing was made 0.011" and no delamination on the metal was allowed. That sample showed hardly any counts above 30 pc all the way up to 40 kv and certainly could not be broken down. More samples are being constructed.

To return to this sample, what is thought to be important here is:

- 1) Impending breakdown was heralded by the ever increasing proportion of mid-level counts, namely those around 30 pc to 80 pc. The breakdown did not occur suddenly, but there was a change of the energy histogram extending over about a 15 minute period at 18 kv (each sampling plus recording-time is 300 seconds).
- 2) Note also, that up to the very end, at a given voltage, the total number of counts decreased with time, and the maximum energy of counts decreased with time, but the proportion of counts at higher energy to lower energy increased.
- 3) The specimen, after breakdown could not be used again to repeat the data run. It registered overload at even 1 kv applied voltage. This is quite different than for samples #4 and #9.

SAMPLE #8, GREEN HYSOL

Pinch-off cap, 7.6 cc fill #6, #6 conducting coat, no temperature cycles.

Condition: No statement.

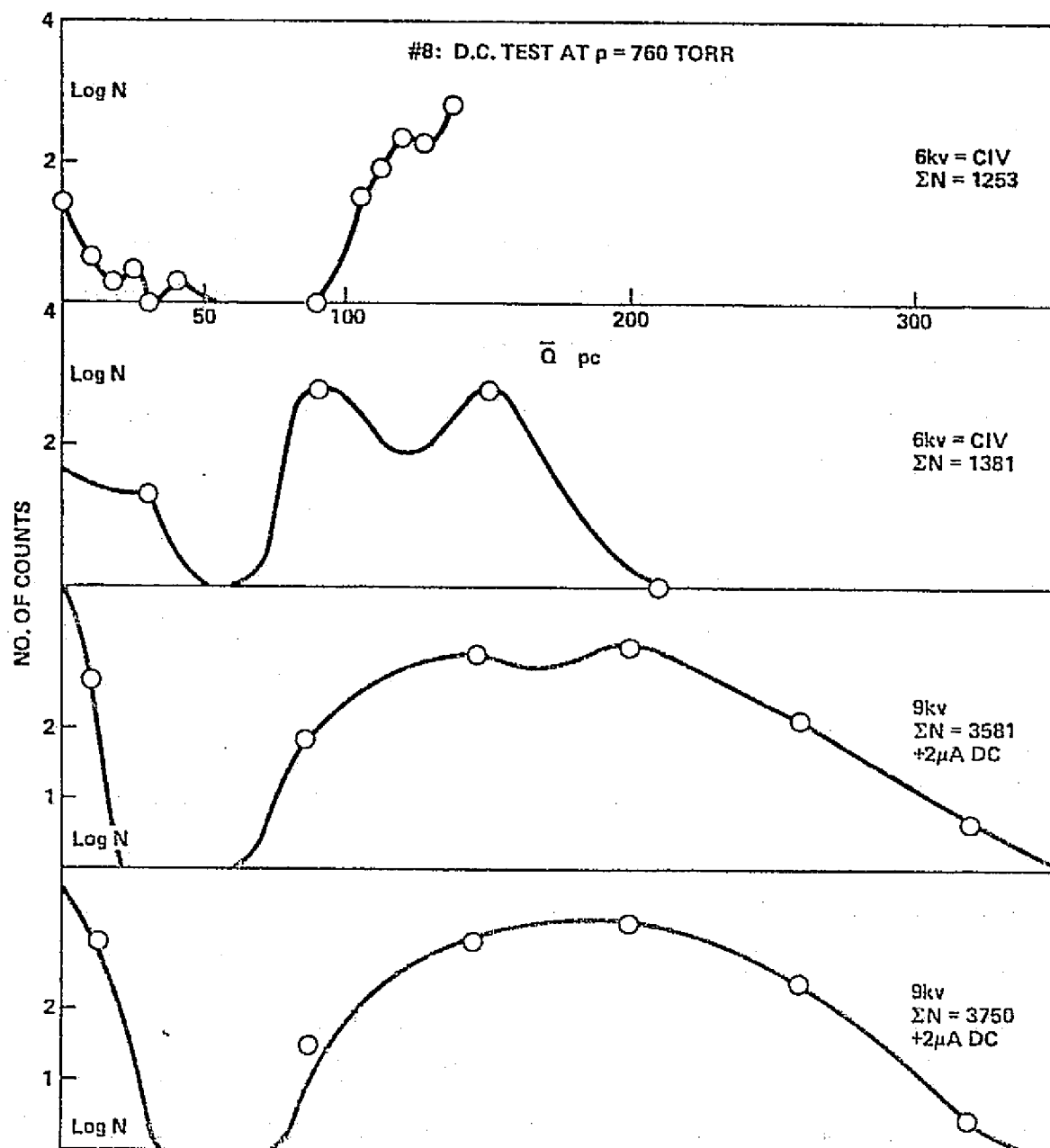


Figure 22a.

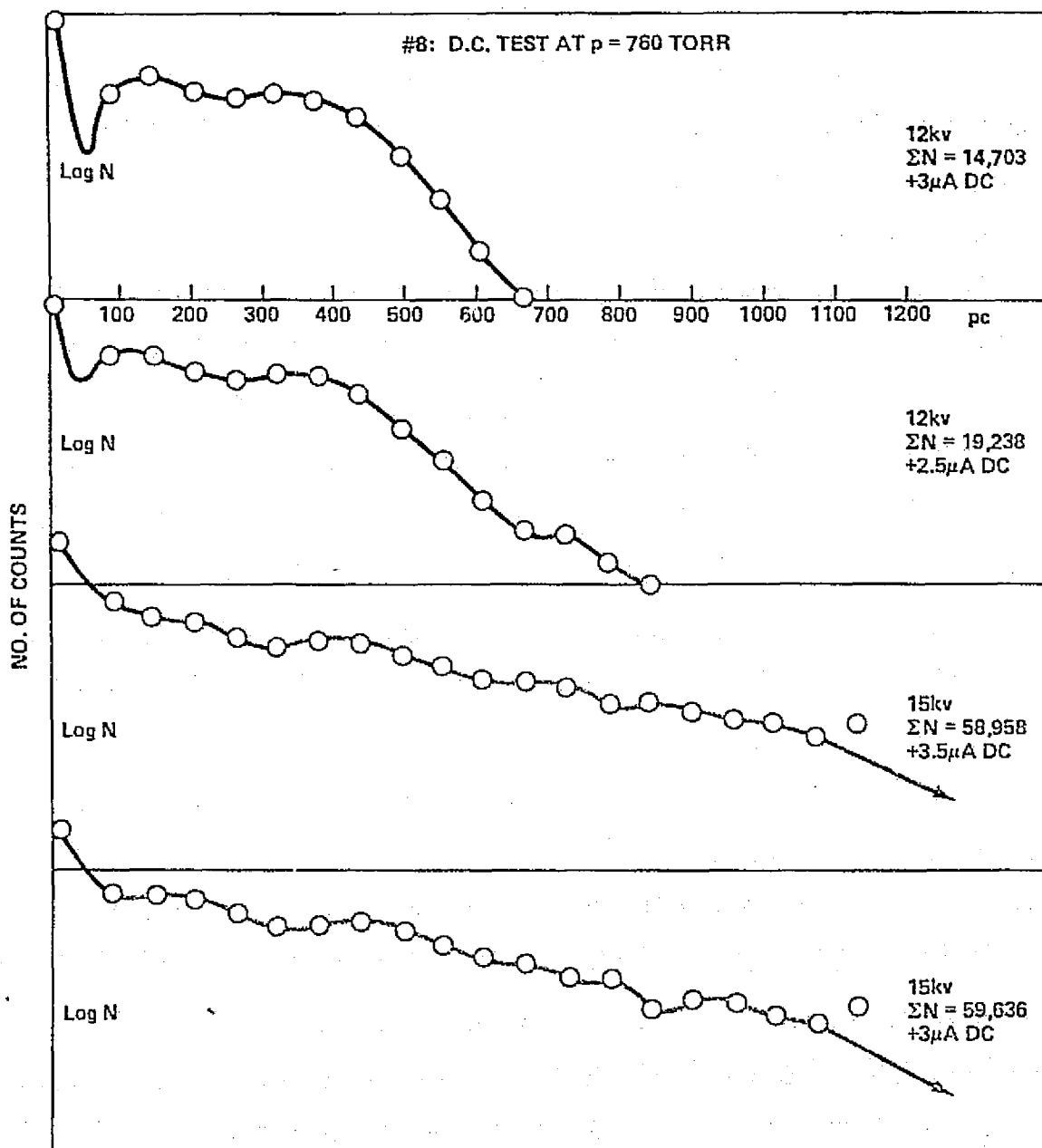


Figure 22b.

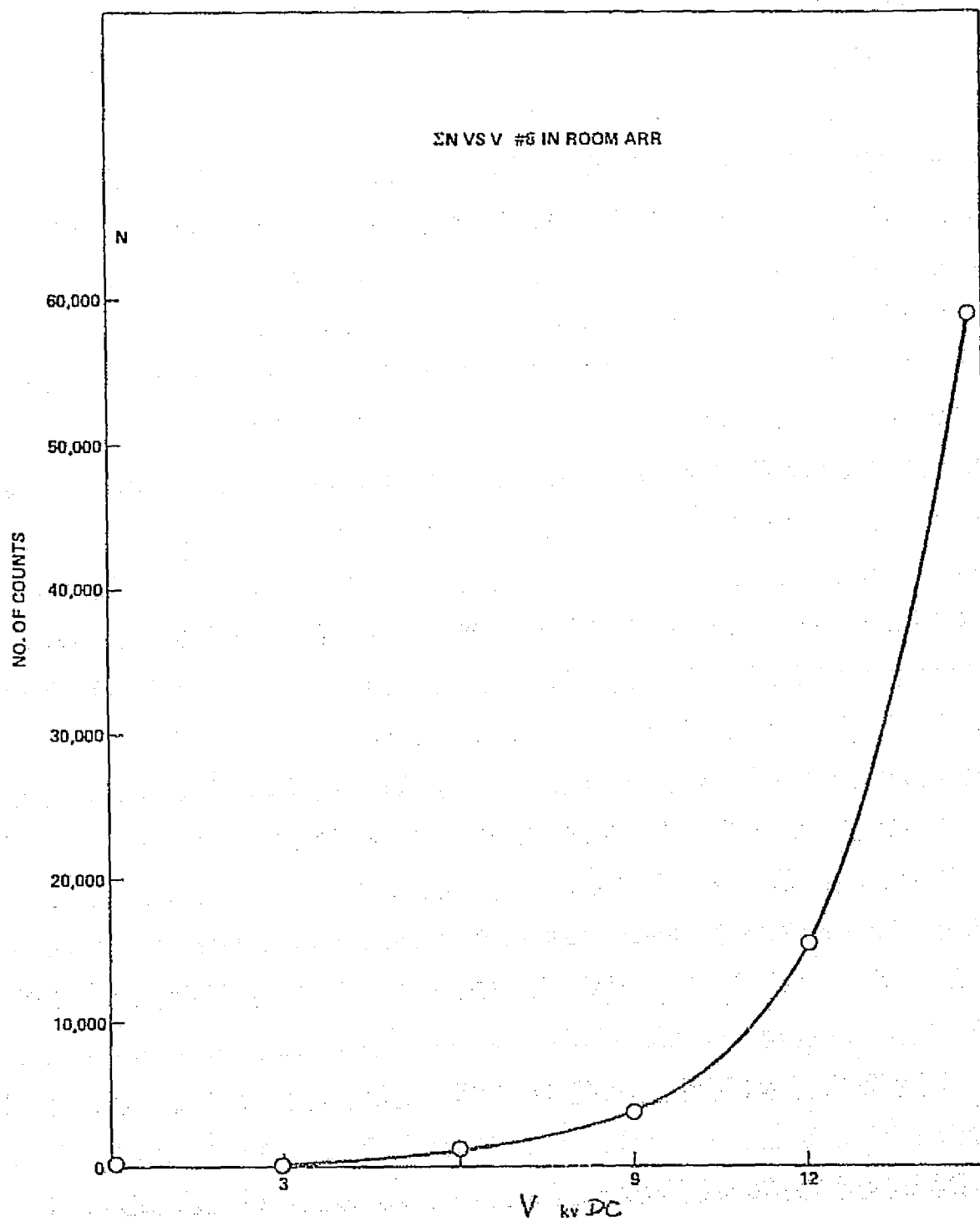


Figure 22c.

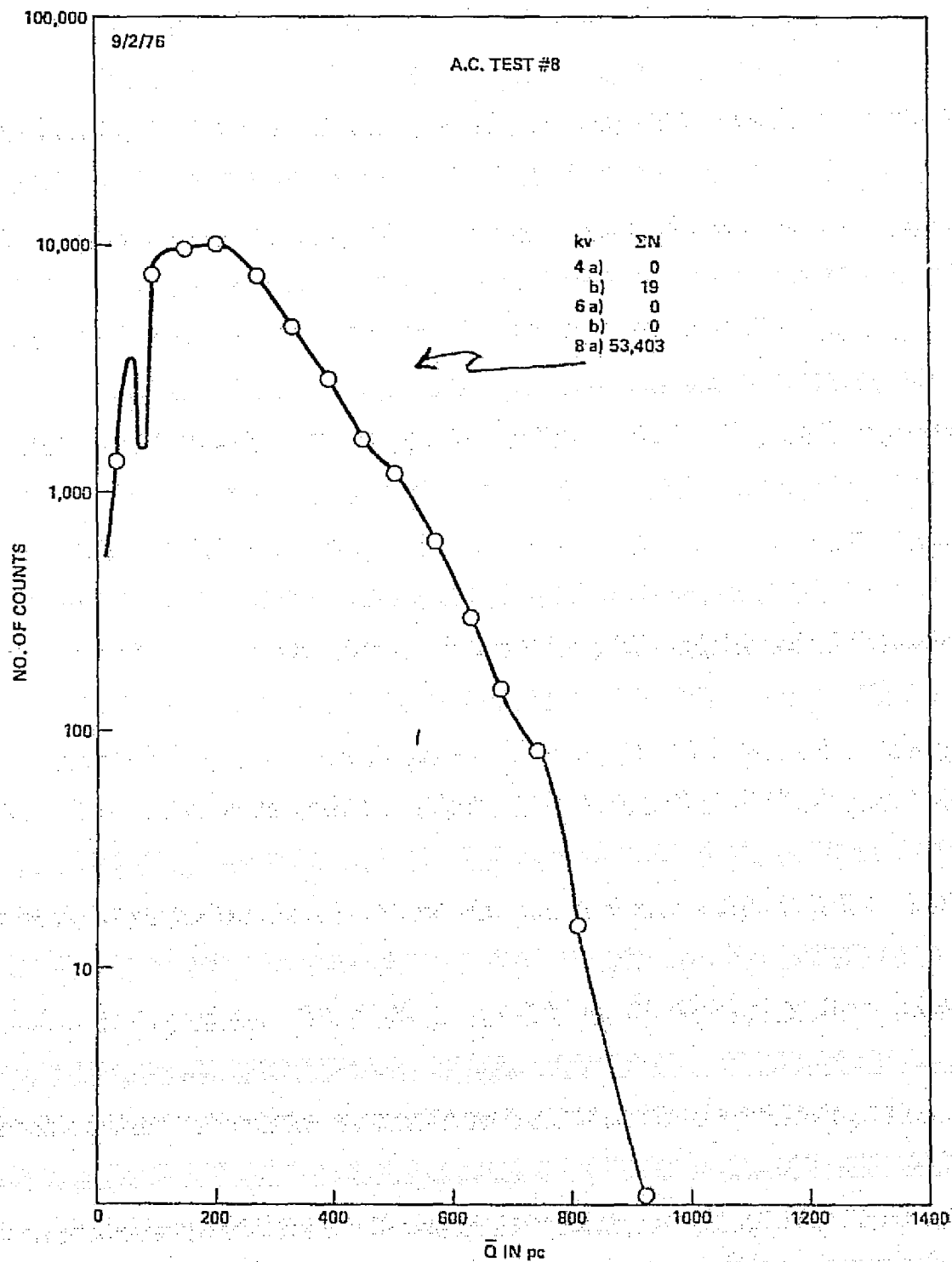


Figure 22d.

SAMPLE #8

This is Green Hysol and shows a quite different behavior than heretofore encountered. During the initial D.C. P.D. tests at atmospheric pressure there was a very high count rate and up to 3.5 microamperes of D.C. current in addition to the P.D. pulses. This D.C. current remained fairly constant between 2 and 3.5 microamperes, while the P.D. pulses increased almost exponentially with voltage. At a given voltage the counts increased slightly with time, and their maximum energy content increased slightly with time. This is opposite to the phenomena found with good insulating materials. In other words, there are plenty of charge carriers in this material to respond to D.C. applied voltage, and one is tempted to characterize it as a type of poor conductor rather than a poor insulator.

The exponential rise of P.D. counts with voltage suggests that there is a bubble² or other type of void in this sample to further complicate matters. After D.C. inception at 6 kv D.C. (1300 counts, most of them between 100 and 200 pc), the count sum plotted out as a straight line on semilogarithmic paper, versus applied voltage, and gave a graph of the type of relationship

$$N = N_0 e^{(V - V_0)/V_A}$$

where V_A is a type of activation energy that calculated out to be 5.5 kv. Yet the A.C. corona inception voltage, unbelievable as it sounds was at 8 kv rms, even though there were already many, many counts at 6 kv D.C.

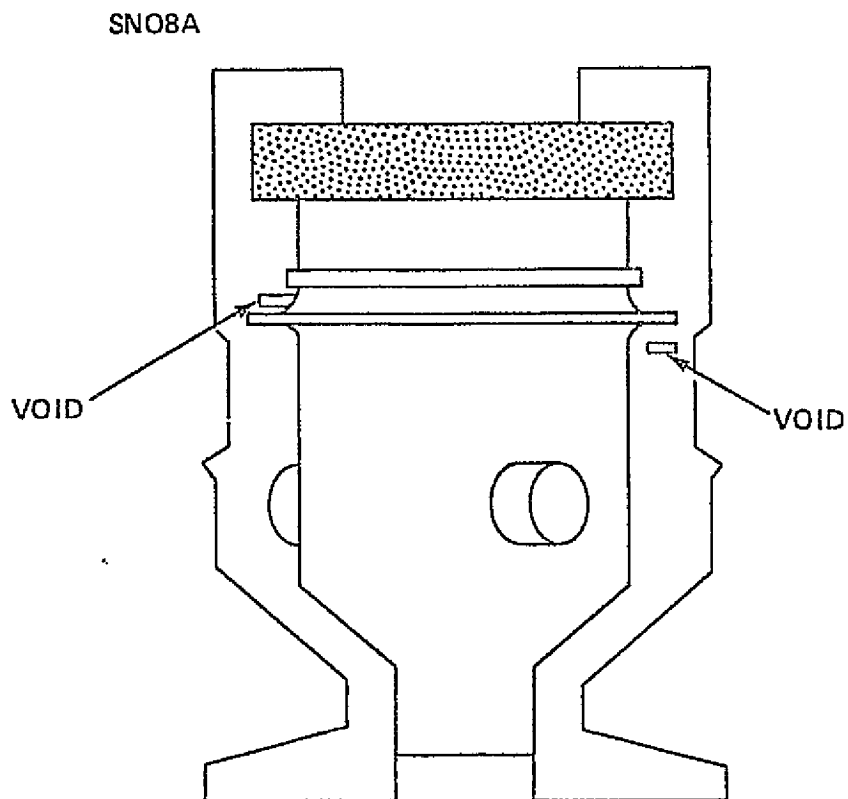
The Black Hysol, sample #3 behaved somewhat similarly. It also had a D.C. leakage current, of about 1 microampere steadily, in addition to a linearly increasing P.D. pulse count with increasing applied D.C. voltage, after 6 kv. However, there were already about 100 P.D. pulses of energies in the 70 pc range at 3 kv D.C. The A.C. inception voltage was at 6 kv rms.

Neither the Green or Black Hysols were taken through the Vacuum Life tests. It is not certain where the conductivity in these materials comes from. Both are Poly-ether types of Polyurethanes, and a mercuric type of catalyst promoter is used to aid the polyol to do better cross linking.

SAMPLE 8 A, CONATHANE EN-11

Pinch-off cap, 7.6 cc fill #6, #6 conducting coat.

Two cavities have supposedly been cut into this sample.



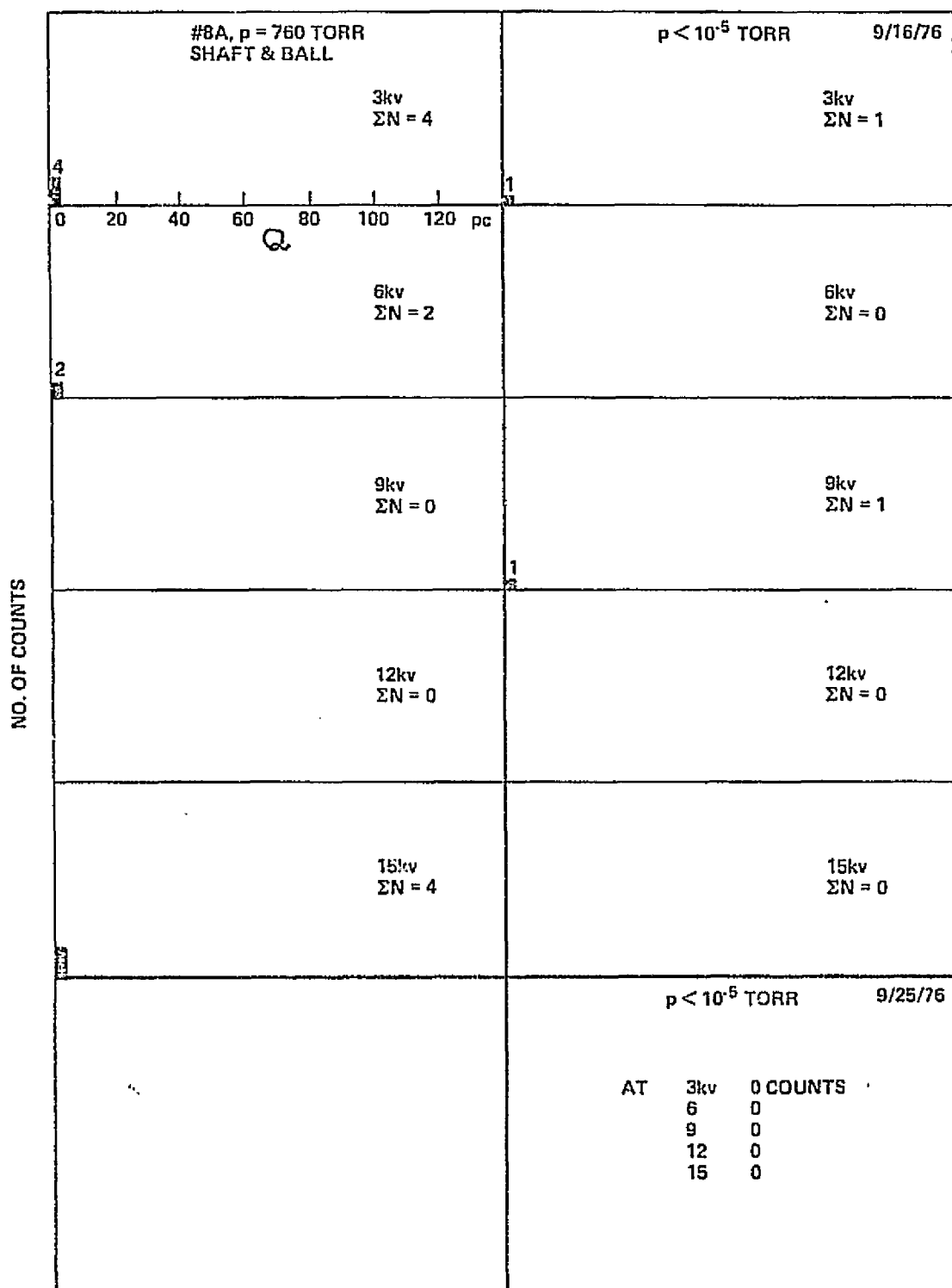


Figure 23a.

<p>$p < 10^{-5}$ TORR 10/1/76</p> <p>#8A</p> <p>3kv $\Sigma N = 0$</p> <p>0 20 40 60 80 100 120</p>	<p>OMIT. INTERFERENCE 10/8/76</p>
<p>6kv $\Sigma N = 4$</p> <p>4</p>	<p>$p < 10^{-5}$ TORR 10/15/76</p> <p>9kv $\Sigma N = 0$</p>
<p>9kv $\Sigma N = 0$</p>	<p>12kv $\Sigma N = 0$</p>
<p>12kv $\Sigma N = 0$</p>	<p>15kv $\Sigma N = 0$</p>
<p>15kv $\Sigma N = 3$</p> <p>21</p>	<p>18kv $\Sigma N = 2$</p> <p>1</p>
	<p>20kv $\Sigma N = 3$</p> <p>2</p> <p>1</p>

Figure 23b.

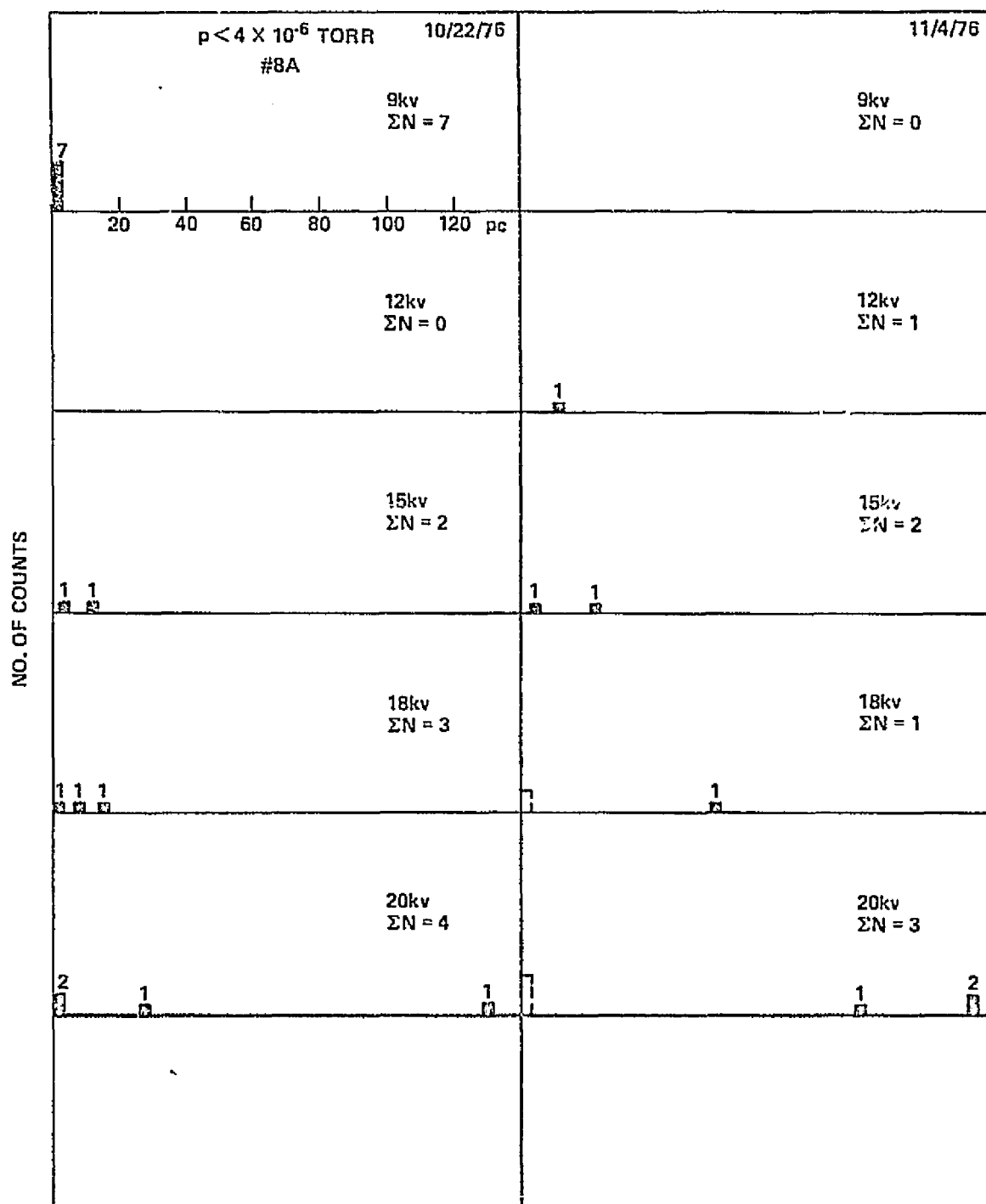


Figure 23c.

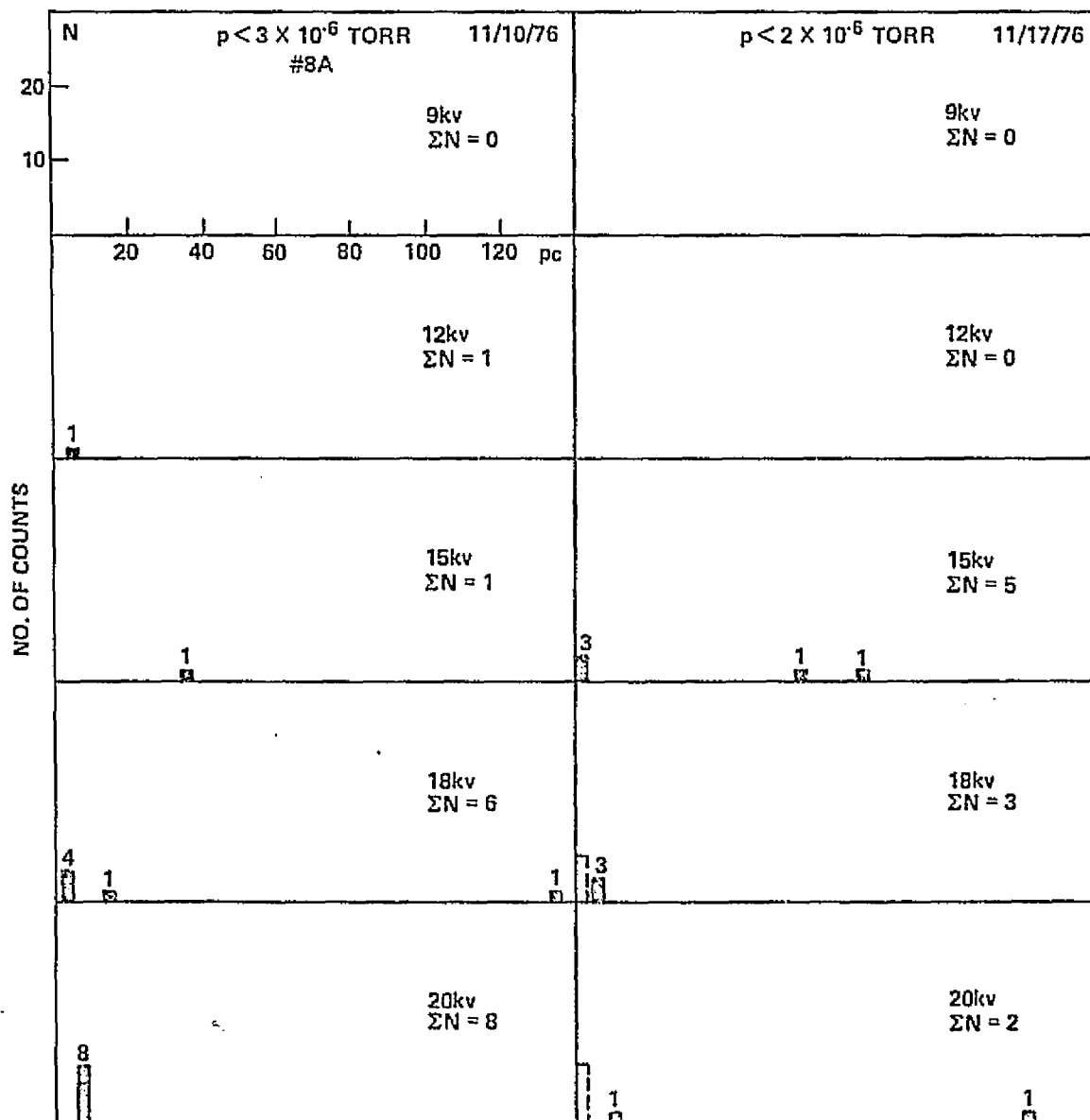


Figure 23d.

NO. OF COUNTS	p < 3 × 10 ⁻⁶ TORR 11/22/76 #8A		p < 5 × 10 ⁻⁶ TORR 11/29/76	
	9kv ΣN = 7		9kv ΣN = 0	
	7			
	12kv ΣN = 5		12kv ΣN = 2	
	2 2	1	1	1
	1			
	15kv ΣN = 2		15kv ΣN = 1	
	1	1	1	
	18kv ΣN = 14		18kv ΣN = 1	
	14		1	
	20kv ΣN = 14		20kv ΣN = 5	
	12			
	1	1	3	1 1

Figure 23e.

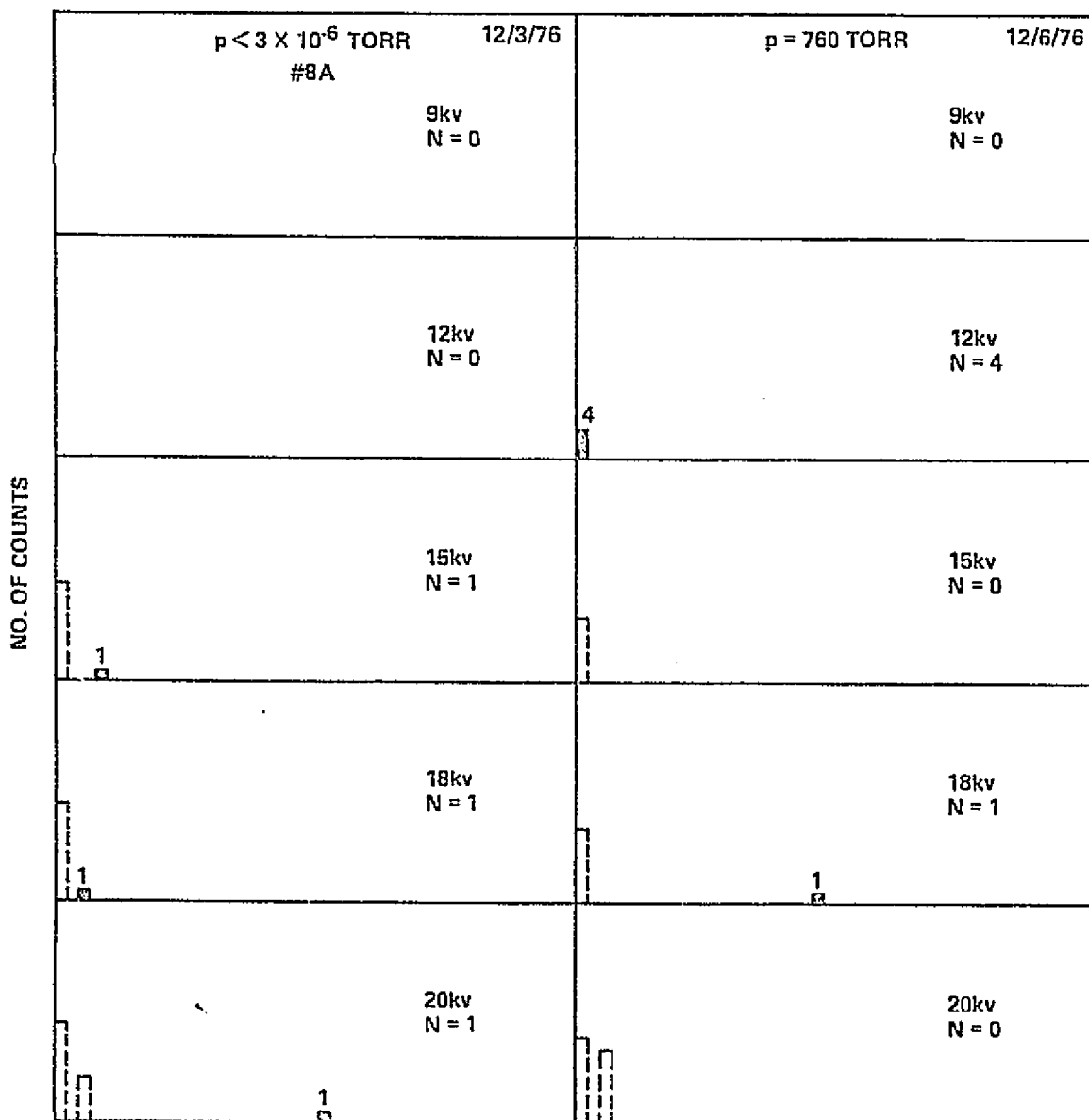


Figure 23f.

SAMPLE #8A

This is Conathane EN-11 with two artificially cut-in cavities. Despite these, the sample is the most quiet one of them all. Yet this specimen had two large defects cut into it, one of them supposedly all the way to the central electrode. The holes after being gouged out, were then plugged and coated over with more resin, perhaps to 1/8" thickness. (The author, as of this writing, has not yet viewed the X-ray taken of the finished specimen.) One can devise two mutually exclusive explanations for the electrically quiet behavior during the Vacuum Life test:

- a) Permeation through the 1/8" wall-thickness for Conathane EN-11 is so slow that the voids were near atmospheric pressure during the entire Life test in vacuum, and the size of the cavities being large, Paschen's criterion for breakdown was not met, and thus the sample was electrically quiet. In other words the test was not nearly long enough for this configuration.
- b) Permeation through the wall was very rapid, so that after one week in vacuum, already the internal pressure in the cavities was at very high vacuum, beyond the Paschen minimum, and so the specimen will remain electrically quiet from then on.

The author feels that explanation a) is the more reasonable one.

- c) An unlikely possibility is that for the particular geometry the discharge magnitude or charge content appearing at the test sample output wires was too small for the sensitivity of the Biddle equipment.

When the geometry of the cavities is exactly determined from the X-ray, then calculations shall be determined on a), b) and c).

In the meantime the empirical fact remains that there were hardly any discharge pulses from this specimen despite supposedly large artificial defects.

SAMPLE #6; SMRD, A MICROBALLOON-FILLED EPOXY

Pinch-off cap, 7.6 cc fill #6, #6 conductive coat.

Condition: No information.

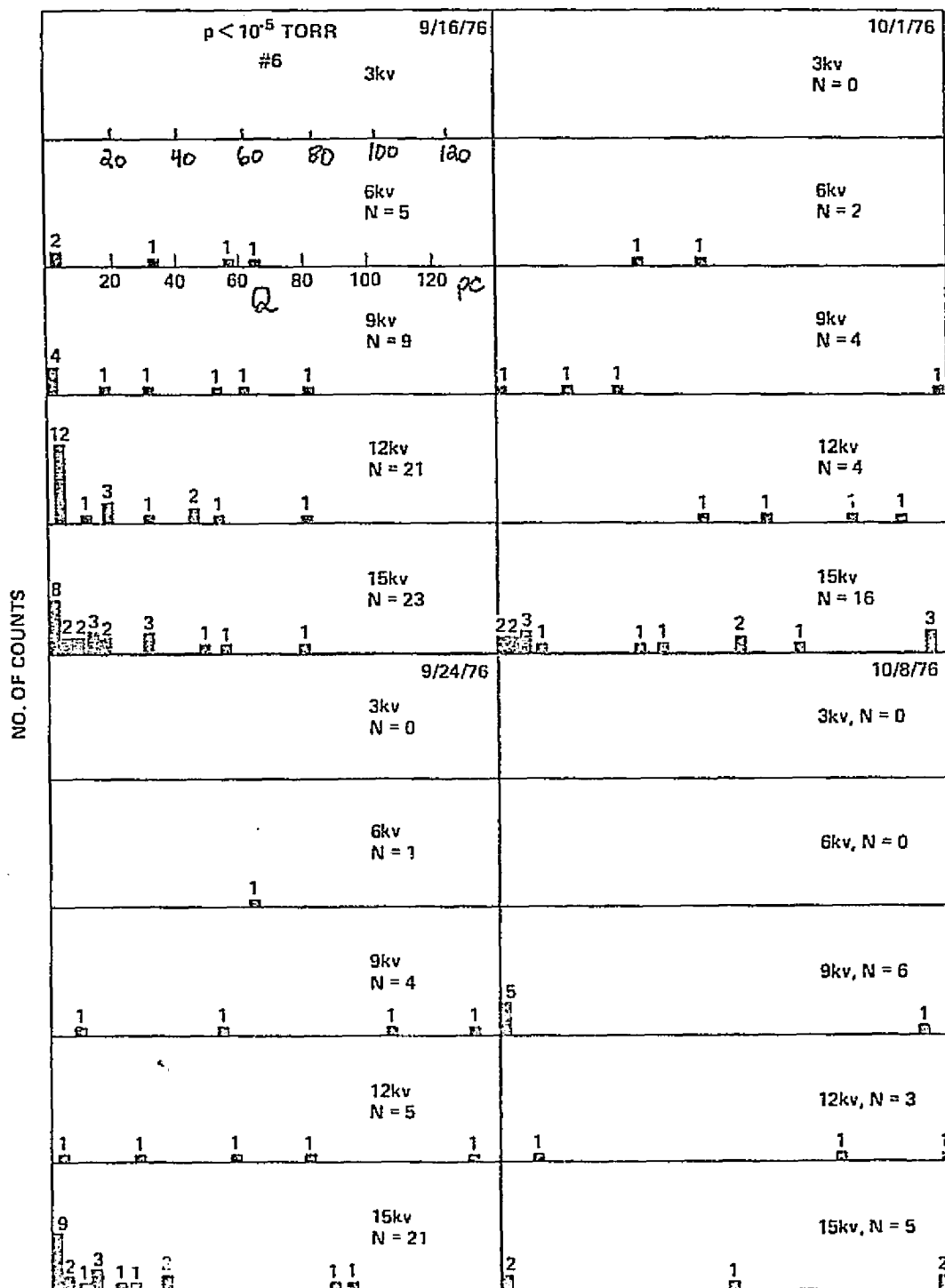


Figure 24b.

Figure 24c.

<p>11/3/76</p> <p>9kv N = 2</p>	<p>10/15/76 #6, $p < 10^{-5}$ TORR</p> <p>9kv N = 2</p> <p>20 40 60 80 100 120</p> <p>8 in pc</p> <p>12kv N = 5</p>
<p>12kv N = 0</p>	<p>15kv N = 6</p>
<p>15kv N = 2</p>	<p>18kv N = 5</p>
<p>20kv N = 8</p>	<p>20kv N = 11</p>
<p>11/10/76</p> <p>9kv N = 1</p>	<p>10/22/76</p> <p>9kv N = 0</p>
<p>12kv N = 0</p>	<p>12kv N = 4</p>
<p>15kv N = 3</p>	<p>15kv N = 3</p>
<p>18kv N = 7</p>	<p>18kv N = 6</p>
<p>20kv N = 17</p>	<p>20kv N = 8</p>

NO. OF COUNTS

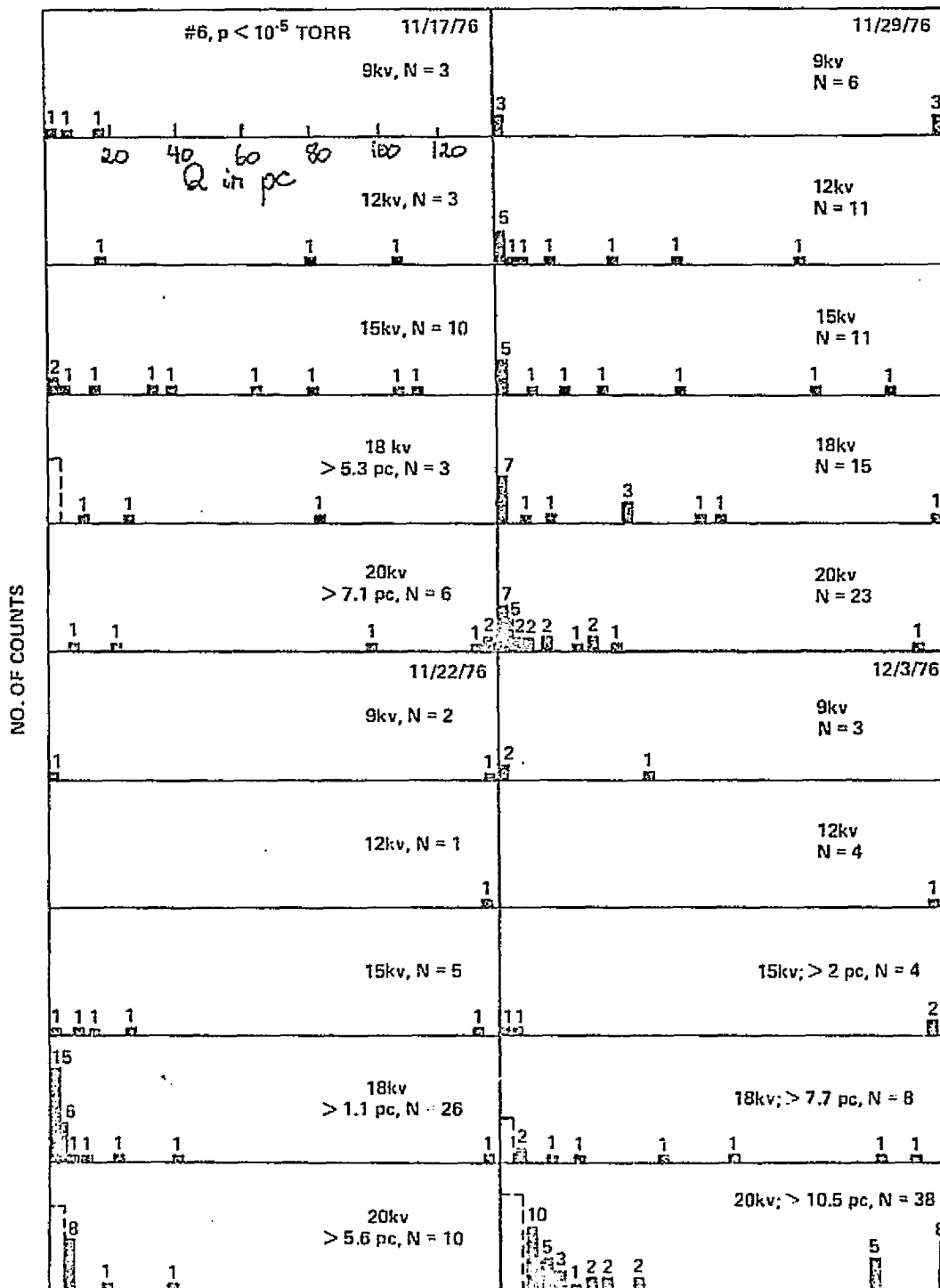


Figure 24d.

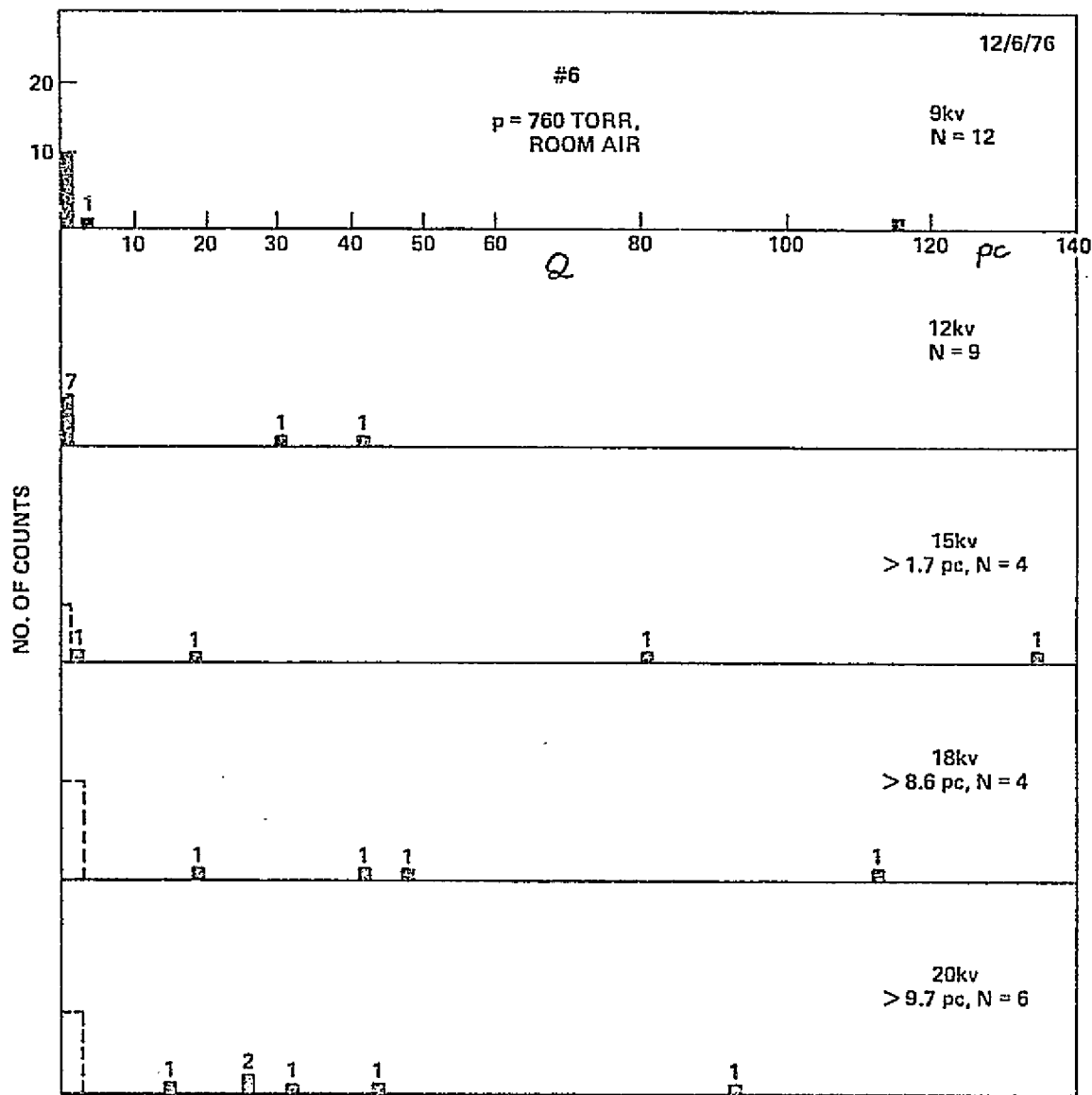


Figure 24e.

SAMPLE #6

This SMRD 432 material is an epoxy filled with glass microballoons. This material takes markedly longer than the others, until the 4th week in vacuum to become "clean." Testing to 20 kv brings back a half dozen counts distributed between 20 pc to 135 pc, and this state of affairs persists pretty well to the end of the test period, even through the 12th week. Admission of room air then produces a reduction of counts, from 38 to 6 counts, at 20 kv. In short, this sample behaved worse in vacuum than in air toward the end of the test, an indication that there are some discharges within the microballoons or some outgasing from the bulk, even after 12 weeks in vacuum. From the standpoint of noise, then, a microballoon-filled potting compound is not a panacea. Whether this is due to the gas within the microballoons or due to small voids here and there between the glass spheres needs to be investigated further. The author has found in an earlier test with mica-sand filler in Sylgard 184 that the filled insulation was vastly more noisy above 3 kv than the pure Sylgard.⁸

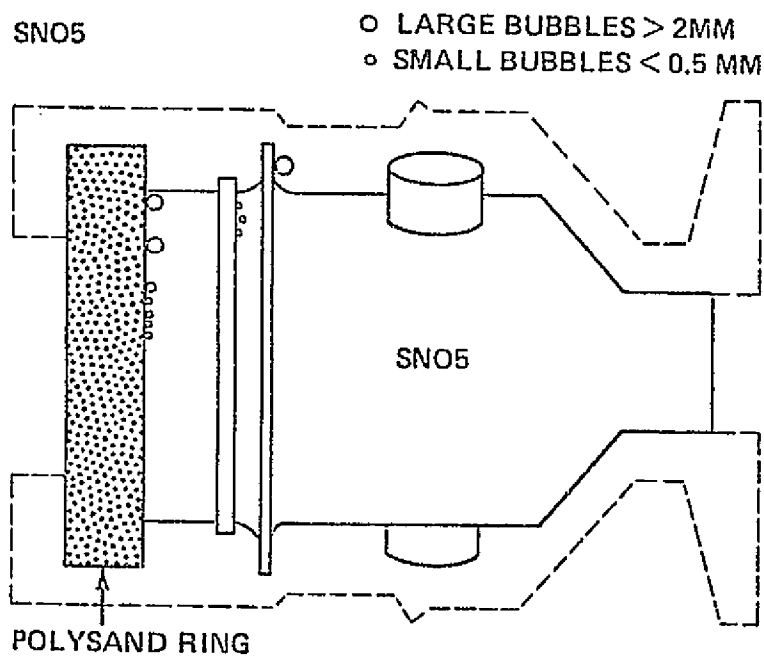
SAMPLE #5, SOLITHANE #2

Pinch-off cap, 7.6 cc fill #6, #6 conductive coat. One temperature cycle.

Condition: 3 bubbles greater than 2 mm near the high voltage electrode.

This sample was placed in the vacuum chamber, but had no high voltage applied to it during the entire Life test.

Its count rate before and after vacuum, compared at 15 kv shows no significant difference.



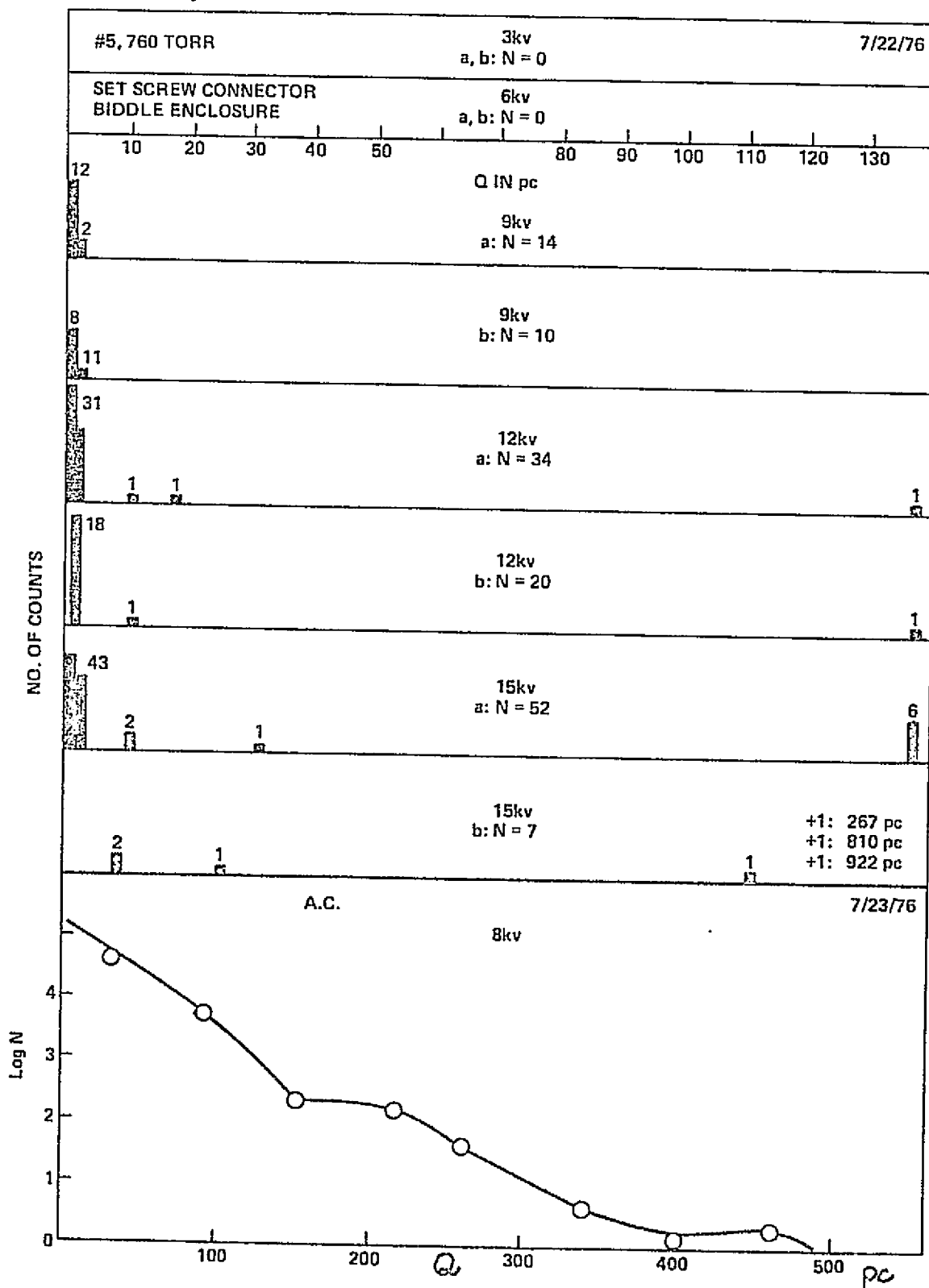


Figure 25a.

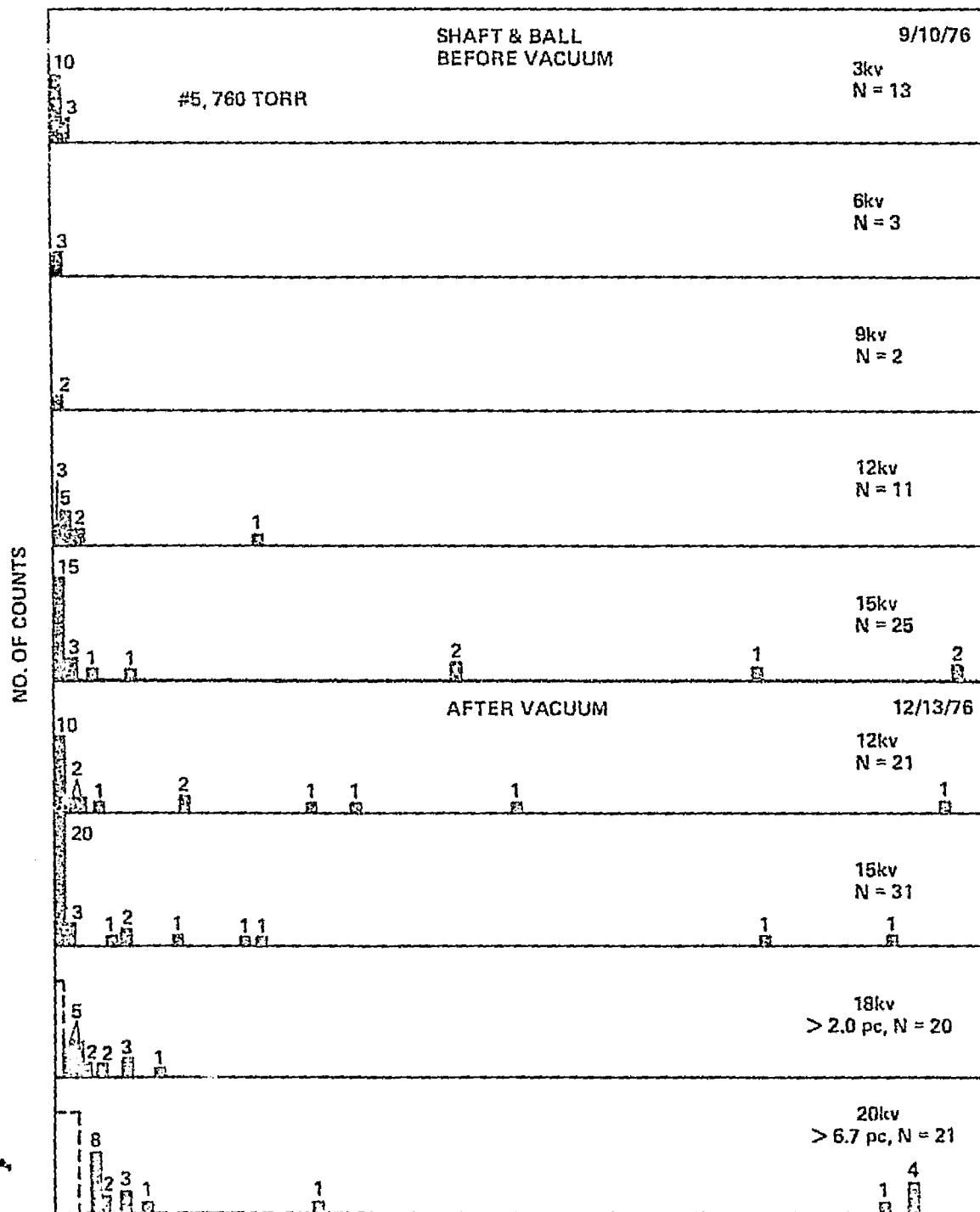


Figure 25b.

EARLIER SEQUENCE OF D.C. PARTIAL DISCHARGE--A.C. PARTIAL
DISCHARGE--VIBRATION TEST--D.C. PARTIAL DISCHARGE TEST

The detailed histograms for one sample, namely #9 are presented here, but nothing very instructive emerges from this.

A summary of all samples in that particular sequence of testing is presented in table form. Some interesting features can now be recognized, and some evidence corroborating conclusions from the Vacuum Life tests can be gathered.

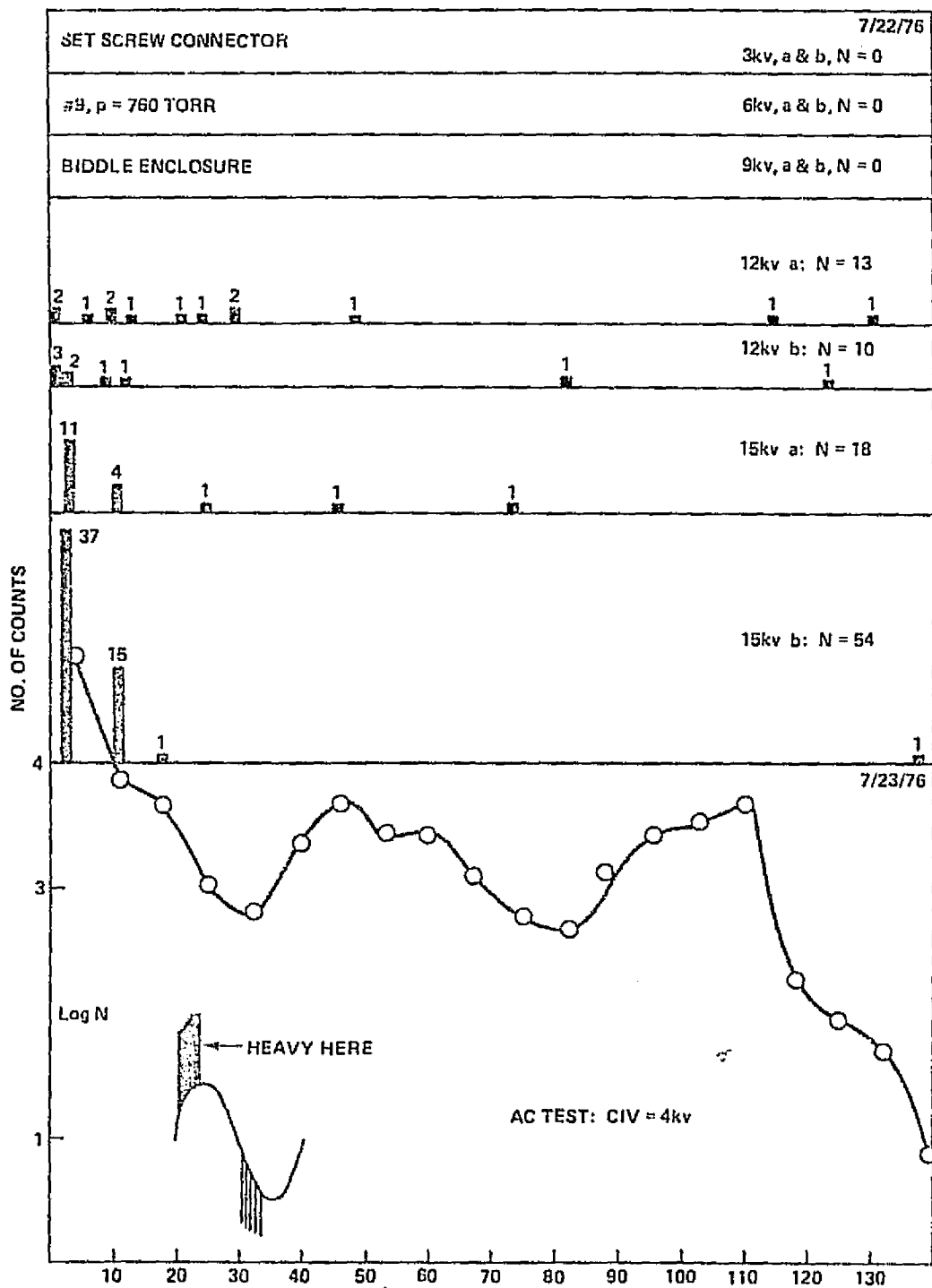


Figure 26a.

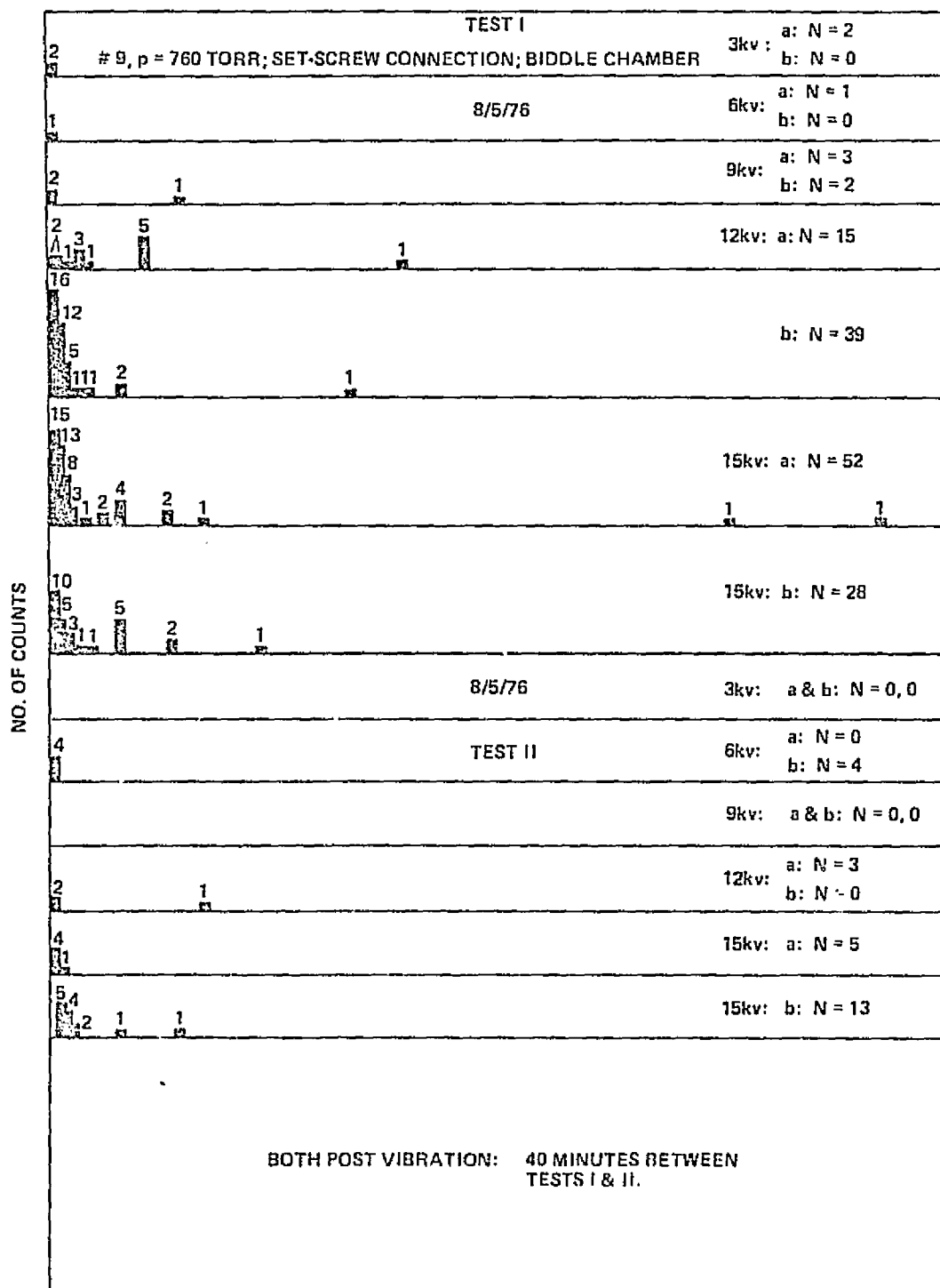

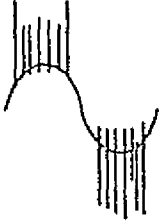
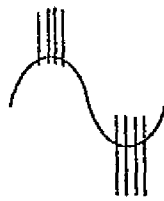





Figure 26b.

TABLE II

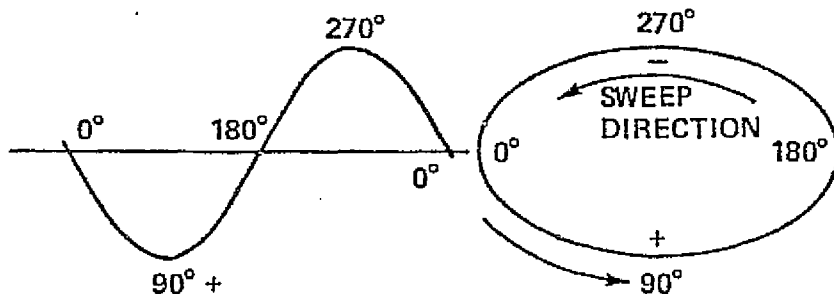
SUMMARY OF

1) DC PD— 2) AC PD— AND 3) POST VIBRATION DC PD TESTS

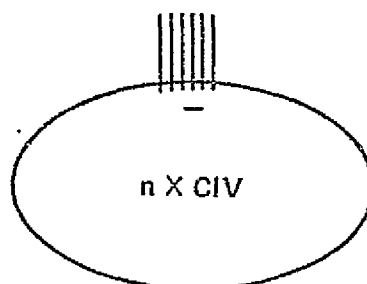
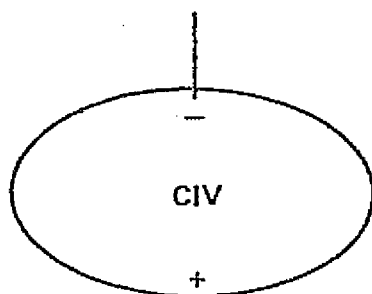
SAMPLE #	DC PD COUNTS		DC START	AC START RMS	AC COUNTS AT START	PICTURE OF AC PD	POST-VIBR. DC PD. COUNTS		ΔN OF DC PD.
	12 KV	15 KV					12 KV	15 KV	
9	a: 13 b: 10	a: 18 b: 54	12 KV	4 KV 5.65	113,285 TO 141 PC	 PROBABLY VOID NEAR AN ELECTRODE	a: 15 b: 39	a: 52 b: 28	SLIGHT INCREASE
8	a: 14,704 +3 μa DC b: 19,239 +2.5 μa DC	a: 58,958 +3.5 μa b: 59,636 +3 μa	6 KV	8 KV 10.4	53,403 TO 1000 PC				
3	a: 12,321 +1 μa b: 11,568 +1 μa	a: 16,515 +1 μa b: 16,123 +1 μa	6 KV	6 KV	20,718				
7	a: 515 b: 526	a: 721 b: 763	6 KV	6 KV	a: 62,075 TO 134 PC b: 30,906 TO 134 PC	 SURFACE CORONA, FROM FIXTURES	8/4/76 a: 441 b: 550 8/5/76 a: 371 b: 459	a: 4,900,455 b: 2,766,693 a: 541 b: 607	NOT CONCLUSIVE
6	a: 37 b: 27	56 37	6 KV	6 KV	a: 86,713 TO 137 PC b: 23,906 TO 150 PC				

SAMPLE =	DC. PD COUNTS		DC START	AC START RMS	AC COUNTS AT START	PICTURE OF AC. PD	POST-VIBR. DC. PD. COUNTS		JN OF DC. PD.
	12 KV	15 KV					12 KV	15 KV	
4	a: 228 b: 237	298 320	6 KV	6 KV	a: 188,252 b: 85,020 TO 1300 PC	 PROBABLY 2 EFFECTS: FIXTURING & CRACK	8/4/76 a: 284 396 b: 325 440		INCREASE
2	a: 0 b: 0	a: 1 b: 4	15 KV	8 KV	37,109 TO 1000 PC	 DELAMINATION	8/4/76 a: 2 a: 11 b: {11} b: 1 8/5/76 a: 4 a: 5 b: 1 b: 5		SLIGHT INCREASE
10	a: 13 b: 3	a: 2 b: 8	9 KV	8 KV	7,886 TO 140 PC	 PROBABLY CAVITY AT INNER ELECTRODE	a: 8 a: 12 b: 1 b: 2		SAME

CRO SWEEP
ORIENTATION
POINT TO PLANE
ARRANGEMENT

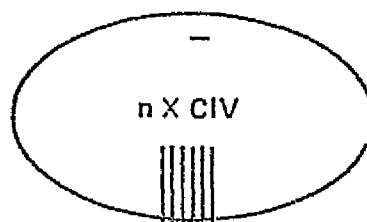
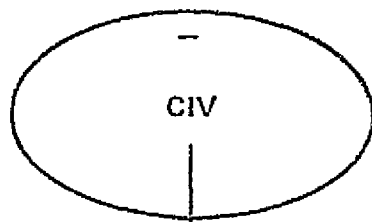
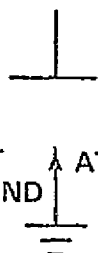


a) POINT HIGH AT VOLTAGE



FOR HIGHER VOLTS,
THERE ARE MORE
SPIKES, SAME HEIGHT

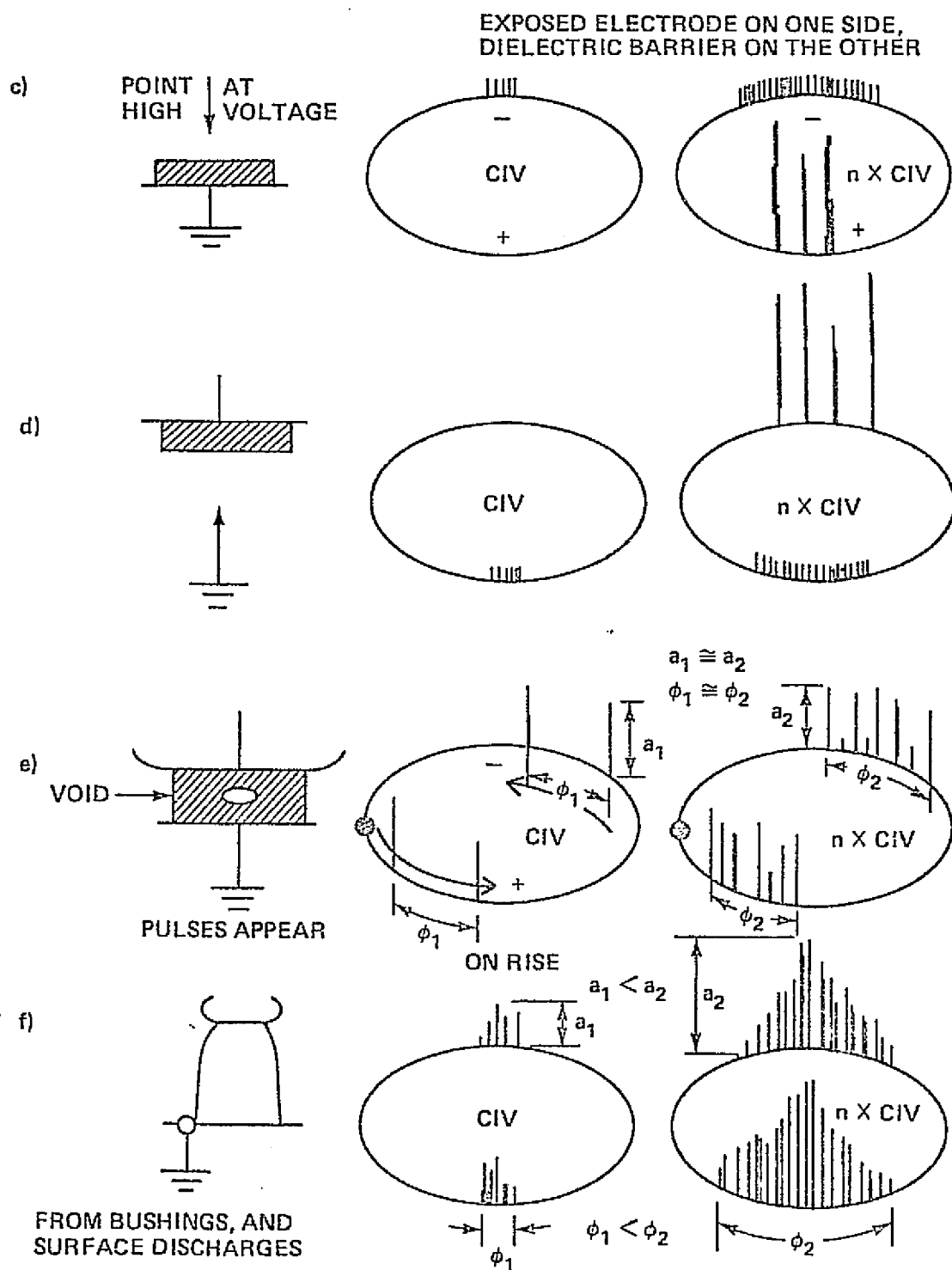
b) POINT GROUND AT



THIS TAKES
HIGHER VOLTAGE

Characteristic AC Corona Patterns

Fig. 27



Characteristic AC Corona Patterns

Fig. 27 cont.

SUMMARY OF THE SEQUENCE D.C. PARTIAL DISCHARGE TESTS --
A.C. PARTIAL DISCHARGE TEST --
VIBRATION TEST --
D.C. PARTIAL DISCHARGE TEST

1. Some samples had a slight increase of the number of counts in the post-vibration D.C. -Partial Discharge test over the pre-test. One can, however, not pin this down as to whether it was due to the A.C. partial discharge test or due to the vibration environment, since no D.C. P.D. test was taken between them. However, the vibration test levels were not severe. Alternating A.C. and D.C. tests are now being planned to investigate how much damage might be done by A.C. testing.
2. Small sketches were made by the experimenter as to the appearance of the A.C. corona pulses on the 60 hertz A.C. Lissajous pattern appearing on the Biddle system oscilloscope. If one compares these to some of the sketches from the Biddle School³ notebook, some earlier conclusions are reenforced. Samples like number #7 and #4 that were plagued by surface discharge problems at atmospheric pressure indeed had their A.C. corona pulses right at the peaks of the A.C. sine wave as advertised. Samples with internal bulk problems like #2 indeed had their A.C. spikes on the rise or fall of the A.C. sine wave.
3. Also the fact that so many of the samples started their D.C. and A.C. corona around 6 kv Dc and 6 kv A.C. rms is felt to be due to surface corona here. Only in vacuum would the corona inception voltages really be significantly due to the bulk defects in those samples. One would, of course, have to be sure that corona does not start in the long cabling leading to the vacuum system or originate from the connections onto the high voltage vacuum feedthroughs. In view of the fact that vacuum fixturing always added a few high energy counts on D.C. testing means that one could expect difficulties here.

XVIII. GENERAL SUMMARY

1. The most obvious conclusion is that during the 12 weeks of the vacuum Life test none of the samples broke down, even though some had definite defects in the insulation.
2. Application of vacuum as the environment at first improved all the units. However, after a few weeks most of them gradually became more noisy again, until just about the week before termination of the test. One would certainly like to know whether that last week's data was real improvement or whether it was just an "accident." Obviously, the author's first vote would be for continuation of the test. It is now planned to bring some of the units back to GSFC to place them in vacuum again for 10 more weeks, and then test again for D.C. Partial Discharge at the General Electric Company. This is especially important for #2 sample, the only one with any significant increase in count rate in vacuum as time went on. (Sample #9, another "noisy" one will be tested at to destruction.) Even for those two units the P.D. pulses were still so few in number that even for those and certainly for the other units like #7 the author would predict a long life of the order of many, many more months and perhaps several years.

Prediction of future length of Life is, of course, risky business. One should really do a very much accelerated test to end of Life and then apply a reasonable multiplication factor for the un-accelerated Life-span. The obvious way to do accelerated testing is to carry on A.C. Partial Discharge testing and constantly applied A.C. voltage, in vacuum. As a conservative start one could do this at the corona inception voltage. One can then reason as follows: By its very nature applied A.C. voltage at corona inception produces two pulses per cycle, or 120 pulses/second for a 60 hertz wave. Per 200 second sampling period this would mean 24,000 as compared to 5 to 10 pulses on D.C. applied voltage over the same time span. Therefore, suppose that the unit lasts for one hour on A.C. before it breaks down catastrophically. Then one can say that it would have lasted 2,400 to 4,200 times as long on D.C. applied voltage or about 110 to 220 days.

Implied in this whole line of reasoning is the idea that damage leading to breakdown of insulation is indeed caused by bombardment by corona pulses of the walls of internal voids, microvoids and flaws. This is indeed the current view of electric breakdown mechanisms. Insulations

break down long before intrinsic breakdown fields of 2 volts/2 Angstroms or 100 Million volts/cm are reached. This number is an estimate as follows;*

3. The Conathane EN-11 seems to be a very excellent insulating material as witnessed by the quiet behavior of sample 8A. In fact, some diffusion and field strength calculations are planned, to explain why this sample was so well behaved with its artificially cut-in flaws.
4. Each discharge pulse is accompanied by a tiny flash of light. This would not be visible to the naked eye, but would be detected by the very IUE camera that is embedded in the potting material. From that point of view, units like #2 with a delamination, and like #9, must be rejected. It would be very interesting to obtain any now rejected flight-tubes, rejected for reasons of light emission from flaws, and run D.C. Partial Discharge testing on it, to obtain a correlation of observable pulse count rate with the Biddle P.D. equipment and the self-measured objectionable intensity of light emission, due to the pulses.
5. Intermittent D. C. Partial Discharge testing amid the application of A. C. accelerated voltage to cause breakdown would be useful. In this way one could get a model as to what this geometry on the IUE dummy tubes would produce for a D.C. P.D. spectrum (energy histogram) as breakdown approaches. To rely on the histogram with the point-to-plane sample is not too good, since its geometry is different, and hence its charge magnitudes could be different.

*The binding energy of an electron in a polymer might be 2 electron volts, and an order of magnitude estimate of distance between an electron and net positive charge that binds it, is 2 Angstrom units.

XIX. CONTINUATION OF EXPERIMENT after March 3, 1977, (after publication of 9):

1. In order to decide more definitely whether the breakdown at atmospheric pressure of unit #9 at 20 KV DC applied voltage was due to internal bulk breakdown or surface flash-over, testing under oil was instituted. First, an oil of unknown age and history was tried and leakage currents resulted. Then several gallons of the Sun Oil Co.'s inhibited transformer oil D 3146-75 were donated by the James G. Biddle Co., Plymouth Meeting, Pa. The accompanying Table and histograms attest to the fact that this is a viable technique. The counts now are relatively few and the histograms look very similar to those in vacuum for #9. Gone is the breakdown at 20 KV.

The technique will, of course, not distinguish between surface flash-over problems and those due to wide-open, vented, radial cracks. Fortunately, the changed optics of oil immersion permitted one to see for the first time that several smudges of the carbon -containing conductive coating #6 had inadvertantly been smeared on the bottom cross-section of the sample #9. It is suspected that the resultant shortening of the surface insulation path between anode and cathode thus caused the 20 KV flash over.

2. Sample #9 also had AC-DC-AC-DC... testing done on it while under oil. The details of this will be given in the next report. Suffice it to say here, that AC corona inception voltage was around 12 to 14 KV rms, much higher than theretofore, showing that previously measured AC coronq inception voltage was due to surface effects. During 120 minutes of applied AC voltage at CIV and higher, a total of about 6 million pulses were suffered

9 in oil

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IN BIDDLE CHAMBER 2/28/77

5/11/77

IN OIL OF QUESTIONABLE
QUALITY

IN FRESH OIL FROM BIDDLE CO.

KVDC	DC AMPS	COUNTS 200 SEC.
12	4	5,309
15	5-7	45,674
18	6-9	89,357
20	8-11	73,079

COUNTS 200 SEC.
0
3
26
128

p = 76 cm, 3m oil 5/11/77

12KV DC
N=015KV
N=3

3

23

18KV
N=26

1

11

12 1/2

20KV
N=128

Fig 28

2

1

by the sample. DC partial discharge testing interspersed between the AC testing showed no significant change in the DC histogram or evidence of significant damage. One would conclude therefore that this particular EN-11 Conathane unit would last at least several years on 14 KV DC applied voltage.

3. An entire I U E Camera Tube Assembly with actual tube, potted with Conathane EN-11, was tested in the Biddle Chamber in air and found to be surprisingly quiet. The data is given in Table III below. The DC current is due to a resistive potential divider being used, which draws current. When both the UV converter and the anode of the tube are connected to the HV terminal of the Biddle System directly, without the divider, then there is no DC current.

(Not encased)

Linear range of system is up to 132.5 pcoul.

12:00 Noon: HV applied to resistive voltage divider.

<u>DC current</u>	<u>Applied KV DC</u>	<u>Counts</u>	<u>Level</u>
microamp			pc (how many),
4	3	0	
	(1.8 KV to anode)		
7	5	0	
	(3.0KV to anode)		
9	7	5	1.0,1.7(2),2.0, 5.5 pc
	(4.2 KV to anode)		
12	9	5	1.0(2),1.3(2), 3.3 pc
	(5.4 KV to anode)		
16	12	13	1.0(6),,1.1,1.4,1.5,4.4,7.2,8.3, 33.0 pc
	(7.2KV to anode)		
19	14	51	1.0(23),1.1(5),1.3(3), 1.4(3),1.5(2), 1.8,2.1,3.2,3.5,4.7,5.5, 10.3, 14.7, 15.3,15.6,19.8,27.0,38.7,40.1,134.2 pc
	(8.4KV to anode)		

2:30 pm. HV connection to both HV leads, directly:

<u>Applied KV DC</u>	<u>Counts</u>	<u>Level</u>
4.2	0	
5.4	1	1.0
7.2	4	1.0(2),1.3,1.4 pc
8.4	17	1.0(7), 1.1(3), 1.3,1.4,1.5(3), 1.7,2.9,6.4 pc

4. The samples #2, #7, #8A, #5 were placed in high vacuum at GSFC at better than 10^{-7} torr, and 15 KV DC was continuously applied to all samples, from March 17 to May 9, 1977, or for 53 more days or $7\frac{1}{2}$ weeks longer. Sample #4 was left sitting at atmospheric pressure in a dessicator as a control. Vacuum was broken on May 9, the samples transfered to a vacuum dessicator, and taken to General Electric Co., King Prussia, Pa. for further PD testing with the Biddle system.

The results follow in Figures 29 to 33 . A copy of each figure is also inserted behind the previous histograms for that particular sample for ease of comparison. Each figure shows 3 or 4 sets of histograms. First, if some other experimentation was carried out on a particular sample between December 1976 and March 1977, then the last set of histograms in air before March is given. There follows the set for the samples vacuum-fixtured at atmospheric pressure in dry N_2 at GE on 6/1/77.; then the set in vacuum at 2×10^{-6} torr the next day on 6/2/77.

Finally, there is the set taken one week later in the Biddle Chamber in air on 6/9/77.

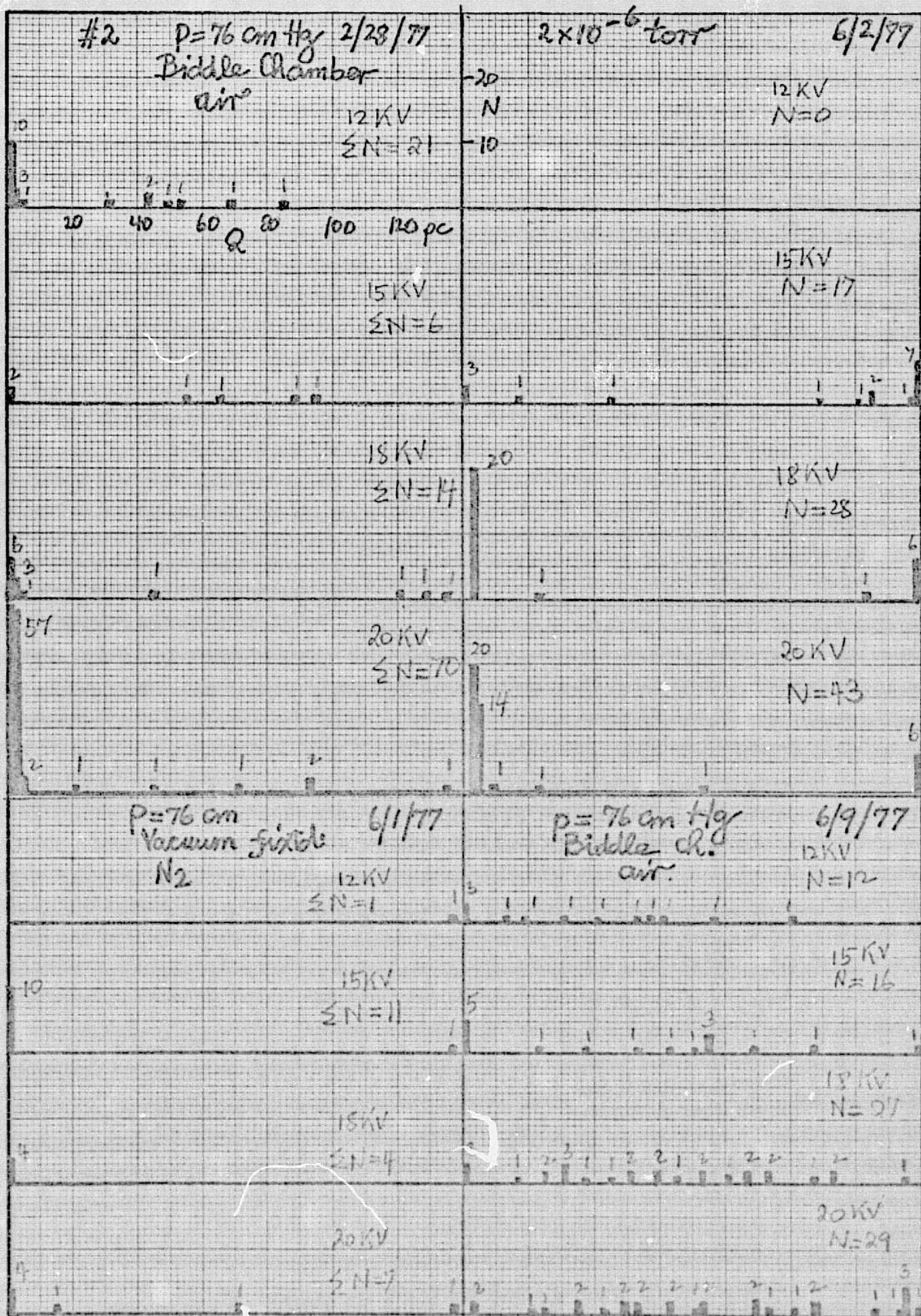
Discussion:

a) Pre-vacuum histograms, vacuum fixtured, 6/1/77:

Control #4: Fairly normal . It is to be remembered that this sample has always shown breakdown problems at atmospheric pressure at 18 KV and 20 KV and DC leakage currents at these voltages.

#2: As expected. Very few counts.

#7: As expected at 12 KV and 15 KV, but then suddenly flash-over at 18 KV with the DC microammeter pegging. This trouble is new. One must note, however, that sample #7 was subjected on 3/2/77 to AC partial discharge testing in air



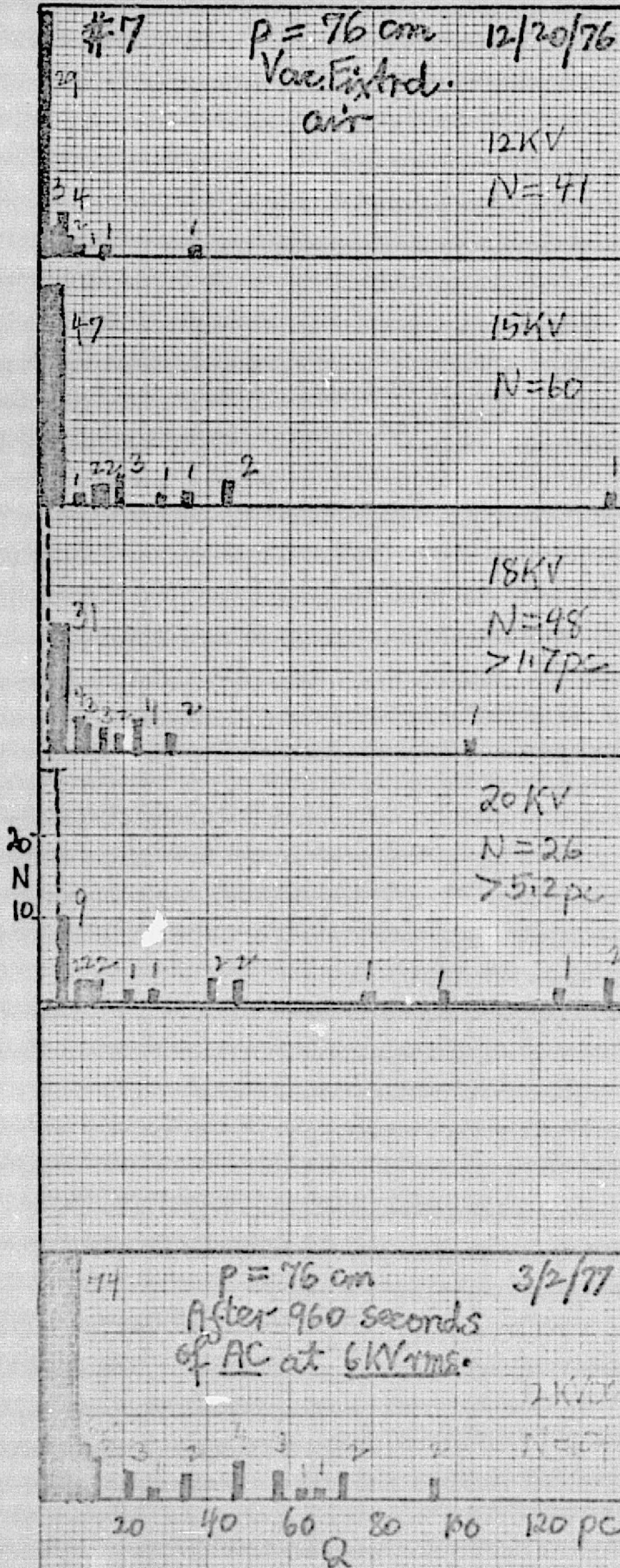
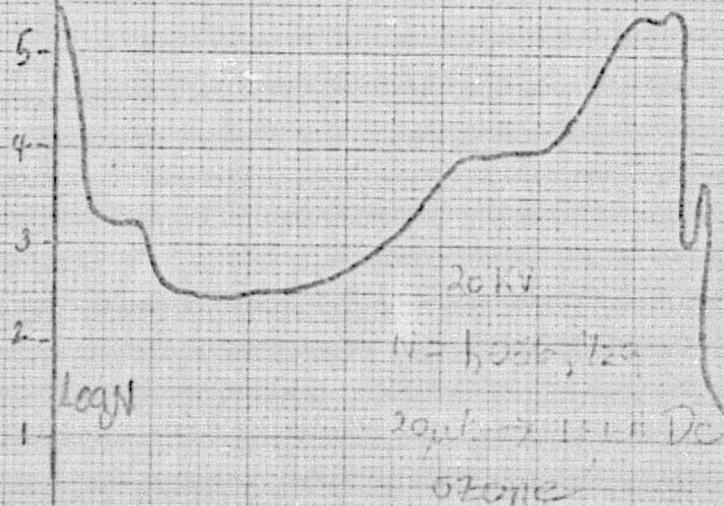
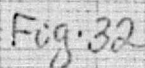
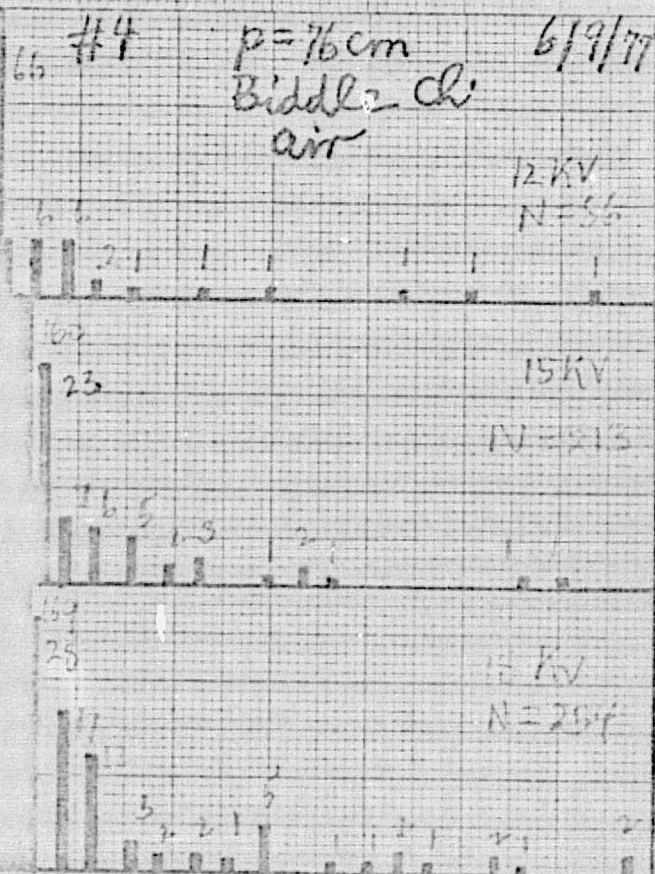
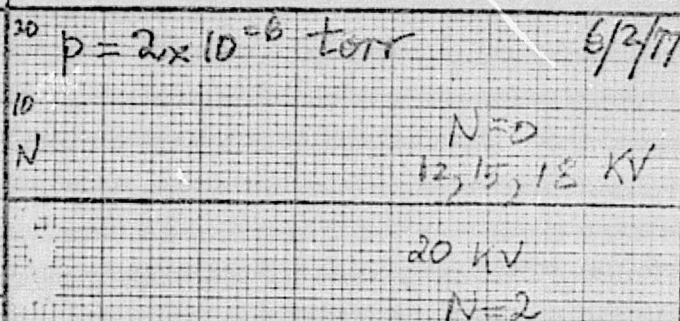
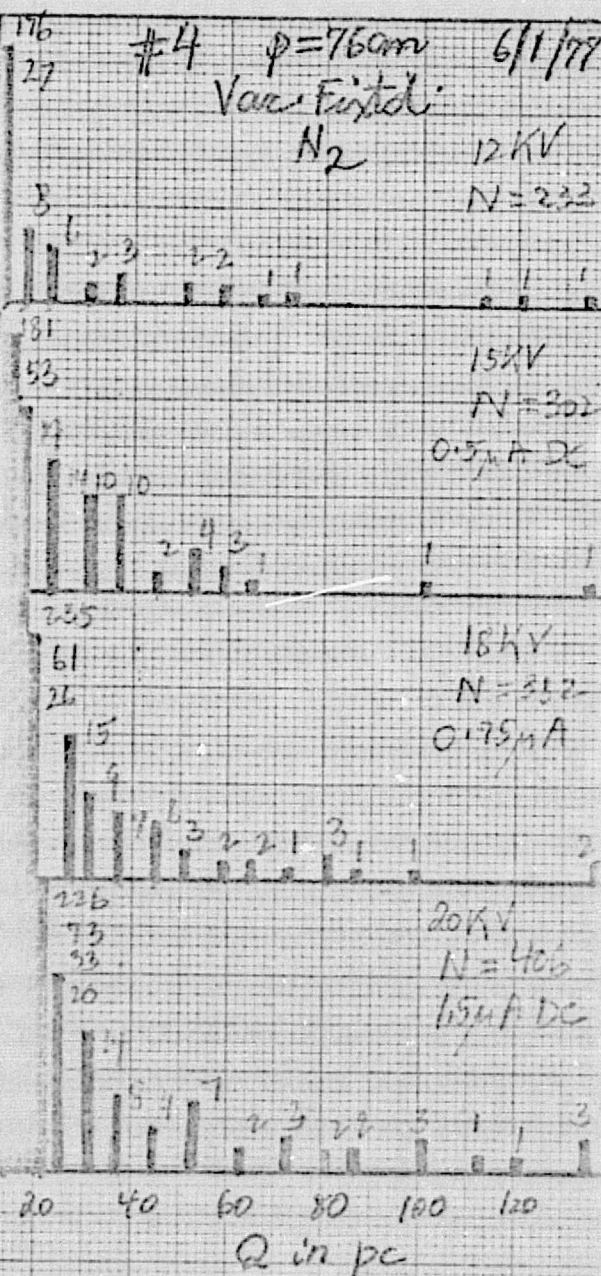


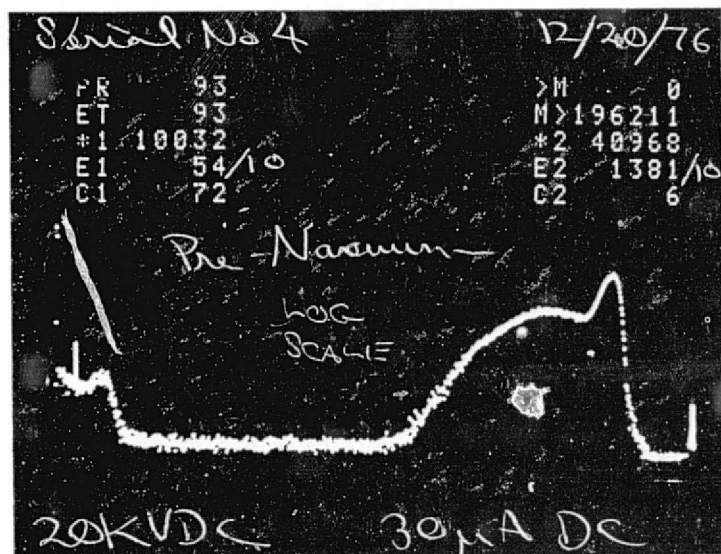
Fig 30 a)



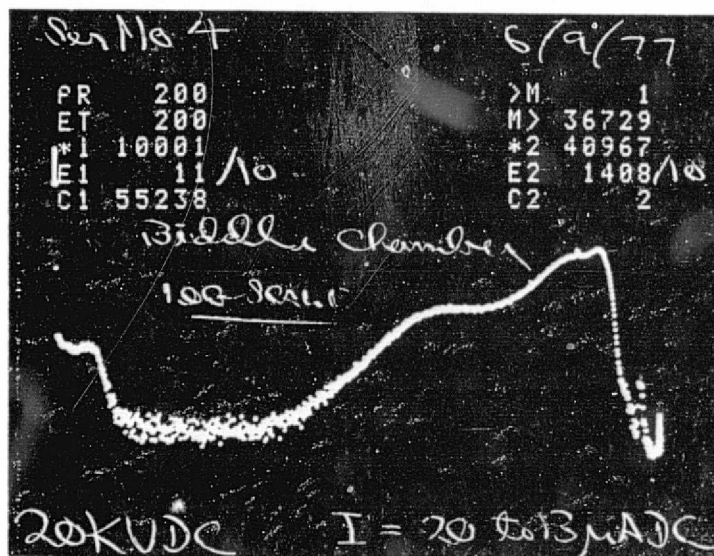
20KV
N = 4



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12/20/76 : # 4 BREAK DOWN HISTOGRAM, $p=76$ cm Hg, 20KV



6/9/77: SAME AS ABOVE, AFTER 53 MORE DAYS IN
VACUUM WITH 15KV APPLIED
CONTINUOUSLY.

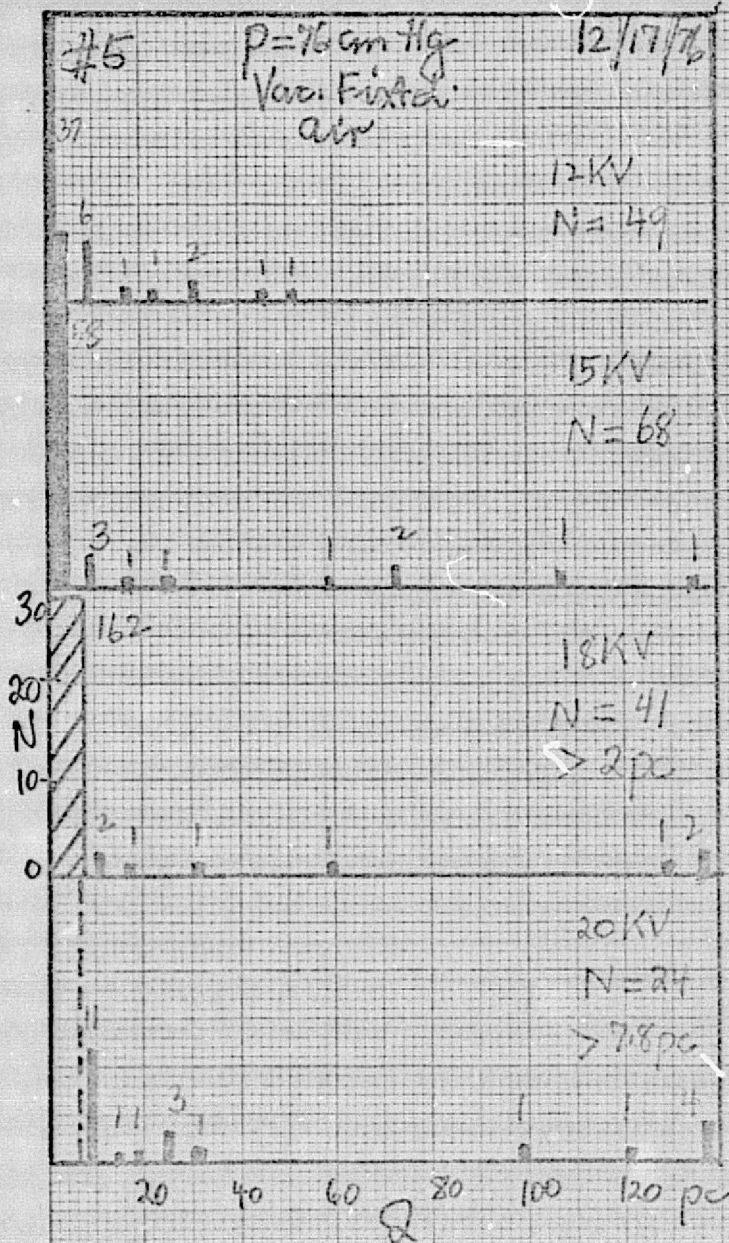
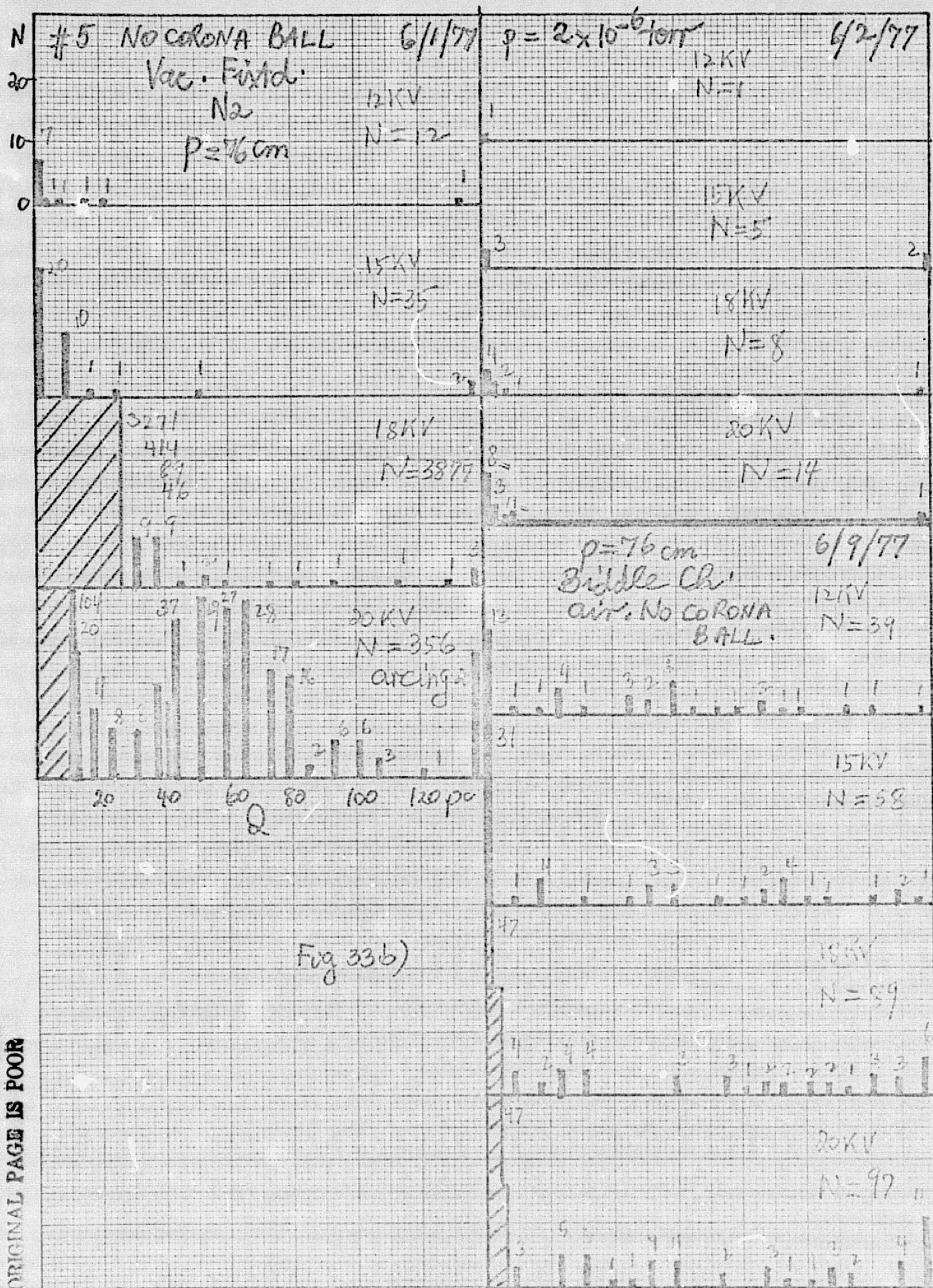


Fig 33a)

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at 6 KV rms for 960 seconds. Following this, its DC histogram in air at 12 KV DC on 3/2/77 had more counts and a greater percentage of higher energy ones than before. Possibly some damage or surface tracking may have taken place.

#8A: As expected, very quiet

#5: This looks much worse at 18 KV and 20KV than heretofore. It is to be remembered that #5 in the previous 12 weeks of Vacuum Life test was in the vacuum system, but had no high voltage applied to it continuously. The 7½ weeks in vacuum, with 15 KV continuously applied was the first high voltage stress for this sample for any length of time. So perhaps there too some damage has taken place.

b) Vacuum Histograms, 6/2/77.

All samples look good. In other words, the histograms look similar to the ones at the end of the previous 12 weeks of Life test, each with its own individuality, however, without exhibiting further deterioration, not even the delaminated sample \$2. This is reassuring for flight considerations.

c) Histograms in air in Biddle Chamber, one week later, 6/9/77.

Control #4: This still has its breakdown problem at 20 KV. Photographs of the 20 KV histogram in December 1976 and June 1977 are reproduced to demonstrate the remarkable reproducibility of behavior.

- #2 : Very disturbing. Suddenly and for no obvious reason, the histograms have a large number of counts over the entire charge range. This new appearance of counts between 30 pc to 140 pc can not be explained except to hypothesize that some surface contamination has deposited on the sample.
- #7 : Also disturbing. Whereas before at 12 KV there were no pulses above 31 pc, now there are twenty-one pulses between 30 and 80 pc, and this gets worse as higher voltages are applied. There was no flash-over at 18 KV this time, but there were many counts.
- #8A : Quiet as always; so the Biddle system and the connecting fixtures are behaving normally.
- #5 : Also disturbing. At 12 KV and 15 KV prevacuum, there were only one or two pulses above 30 p c, now there are dozens.

In conclusion, one can state that the 7½ weeks longer of Vacuum Life test show no further degradation of insulation integrity in vacuum. However, subsequent testing in air at ambient pressure indicates some source of increased discharge activity, possibly surface contamination. A thorough cleaning with alcohol and freon, of the samples is planned, and then more Vacuum Life test with 15 KV DC applied.

PART B:

**DIFFUSION OF GASES THROUGH
VARIOUS SILICONE RUBBERS**

DIFFUSION THROUGH THICK WALL S.

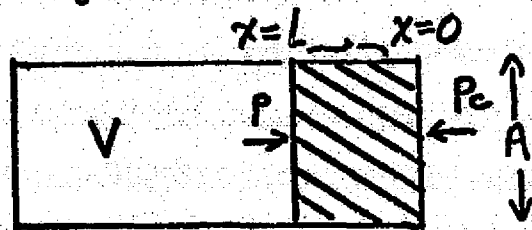
a.) Improved Mathematical Theory for Diffusion and Permeation.

In the previous annual report and GSFC document X-711-75-221¹⁰ permeation coefficient measurements were reported for several potting compounds. The equations presented were stated to be approximate solutions to the diffusion equation, and were applicable for the steady state case, in the long-time situation, for the geometry of thin permeation wall and large void. The experimental permeation chambers were built accordingly with about 0.2 cm thin wall and cavity of volume 32 cm³. The permeation constants obtained this way are held to be correct.

The above-stated conditions for the approximate equations to hold really means that the parameter H , which is the ratio of the amount of penetrating gas in the wall to that in the cavity volume V be small. The ratio H can be written as KAl/V , where A is the cross-section area and l is the thickness of the wall, and $K = C/C_g$, where C and C_g denote the concentration of penetrant in the wall and the volume V respectively when the two phases are in equilibrium. At one atmosphere of pressure this is the same as solubility S in units of cm³ (STP) cm³ per atmosphere. ($K = S T_p/T_g$, sub-s meaning STP)

Unfortunately, when the approximate equations, especially (7) and (8) in the aforementioned X-document are used to make calculations for thick-walled, small - void cases, such as a bubble deep in a potting compound, then they do not hold and give wrong predictions of time intervals for diffusion. The exact equations are infinite series and are difficult to put in usable form. A recent (1975) article on "Transient Diffusion Through a Membrane Separating Finite and Semiinfinite Volumes" ¹¹ by J.A. Barrie, H.G. Spencer, and A. Quig was found, and the salient portion of that article is here with presented:

Consider a wall of cross sectional area A and thickness l separating penetrant at pressure p in the finite volume V from penetrant at pressure p_0 , which is constant. This is shown in the figure below



In general $p \neq p_0$, and either may be zero; the pressure in V as a function of time t is required. The diffusion equation and boundary conditions are as follows:

$$\frac{\partial^2 c}{\partial x^2} = \frac{\partial c}{\partial t} \quad (1)$$

$$c(l,0) = c_0; \quad c(x,0) = c_1; \quad c(0,t) = c_0 \quad (2)$$

$$D \left(\frac{\partial c}{\partial x} \right)_{x=l} = - \frac{1}{H} \frac{\partial c(l,t)}{\partial t} \quad (3)$$

K and H have already been defined on the previous page. Equation(3) relates the change in the concentration in the volume V to the rate at which penetrant diffuses into the face at $x=l$. The concentration c_1 is initially uniform throughout the membrane. Using the Laplace transformation method the solution for C can be expressed as

$$C(x,t) = c_0 + 2 \sum_{n=1}^{\infty} \frac{(c_1 - c_0)(H^2 + Q_n^2) \sin Q_n + (c_0 - c_1) H Q_n \sin(Q_n x/l) \exp(-D Q_n^2 t/l^2)}{(H + H^2 + Q_n^2) Q_n \sin Q_n} \quad (4)$$

This equation is number (4)

The Q_n are the non-zero, positive roots of $Q \tan Q = H$ (5)

So, the first step in the application of what follows is the solution for the Q 's for a given parameter H .

To illustrate, one considers five special cases of the initial and boundary concentrations designed I,II,III,IV,V, which occur often in experiments. Of these I to IV correspond to a uniform initial con-

centration of penetrant C_i in the wall whilst V is an example of a corresponding non-uniform initial concentration. In what follows, p^X with $X = I, \dots, V$ denotes the pressure of penetrant in the volume of the void.

(I) The wall is initially free of penetrant; the initial pressure in V is p_0 , and a constant zero pressure is maintained on the other side of the membrane so that $C_i = C_0 = 0$; $C_0 \neq 0$ and from equation (4)

$$C = 2C_0 \sum_{n=1}^{\infty} \frac{H \sin(Q_n x/l) \exp(-DQ_n^2 t/l^2)}{(H+H^2+Q_n^2) \sin Q_n} \quad (6)$$

This result is also obtained by transformation of the corresponding solution for heat flow in a slab. Evaluating C at $x=l$ and defining the Henry's law solubility as $\bar{C} = C/p$, one obtains for the pressure of penetrant in the void volume

$$\frac{p^I}{p_0} = \sum_{n=1}^{\infty} A_n^I \exp(-DQ_n^2 t/l^2) \quad (7)$$

where

$$A_n^I = \frac{2H}{H+H^2+Q_n^2} = \frac{2\cos Q_n \sin Q_n}{Q_n + \cos Q_n \sin Q_n} \quad (8)$$

(II) The membrane is first equilibrated with penetrant to establish a uniform concentration throughout; the pressure on the surface $x=0$ is reduced to zero and maintained constant so that $C_i = C_0 \neq 0$; $C_0 = 0$. Proceeding as in case (I) one obtains

$$\frac{p^{II}}{p_0} = \sum_{n=1}^{\infty} A_n^{II} \exp(-DQ_n^2 t/l^2) \quad (9)$$

where

$$\begin{aligned} A_n^{II} &= \frac{2(H^2 + Q_n^2) \sin Q_n}{(H+H^2+Q_n^2) Q_n} = \frac{2 \sin Q_n}{Q_n + \cos Q_n \sin Q_n} \\ &= \frac{2H^2}{Q_n \sin Q_n (H+H^2+Q_n^2)} \end{aligned} \quad (10)$$

(III) The wall is equilibrated with penetrant as in (II); the pressure on the surface $x = 0$ is maintained constant whilst that in the void is reduced to zero initially so that $C_i = C_o \neq 0$; $C_o = 0$ and the pressure p^{III} in the void is given by

$$1 - \frac{p^{III}}{p_o} = \sum_{n=1}^{\infty} A_n^I \exp(-DQ_n^2 t/l^2) \quad (11)$$

Thus the function $(1 - p^{III}/p_o)$ decays with time at exactly the same rate as the function p^I/p_o .

(IV) The wall is initially free of penetrant; the initial pressure in the void is zero and a constant pressure is maintained on the surface $x = 0$, so that $C_i = C_o = 0$; $C_o \neq 0$ and

$$1 - \frac{p^{IV}}{p_o} = \sum_{n=1}^{\infty} A_n^{II} \exp(-DQ_n^2 t/l^2) \quad (12)$$

and the function $(1 - p^{IV}/p_o)$ decays at the same rate as p^{II}/p_o .

Equations (7), (9), (11), and (12) may be represented by the single equation

$$f^X(p) = \sum_{n=1}^{\infty} A_n^X \exp(-DQ_n^2 t/l^2) \quad (13)$$

where

$$f^X(p) = p^X/p_o \quad \text{for cases } X = I \text{ and } II$$

and

$$f^X(p) = (1 - p^X/p_o) \quad \text{for cases } X = III \text{ and } IV$$

Also

$$A^I = A^{III} \quad \text{and} \quad A^{II} = A^{IV}.$$

For large t the first term of the summation dominates, and $f^X(p)$ decays exponentially with time so that

$$\ln [f^X(p)] = \ln A_1^X - DQ_1^2 t/l^2. \quad (14)$$

Further if H is sufficiently small, $\tan Q_1 \approx Q_1$, $Q_1^2 \approx H$ and equation (14) becomes

$$\ln [f^X(p)] \approx \ln A_1^X - DHt/l^2 \quad (15)$$

$$\text{where } A_1^I = A_1^{III} = \frac{2}{2+H} \quad \text{and } A_1^{II} = A_1^{IV} = \frac{2(1+H)}{2+H} \quad (16)$$

Remember, there H is small.

(V) Finally, a special case is considered of a non-uniform initial concentration C_i in the wall at $t = 0$;

$$C_i = x/l C_0; \quad C_0 = 0.$$

This means a linear concentration gradient is established in the wall at $t=0$. By the Laplace transformation one gets that

$$C = 2C_0 \sum_{n=1}^{\infty} \frac{H^2 \sin(Q_n x/l) \exp(-DQ_n^2 t/l^2)}{(H + H^2 + Q_n^2) Q_n^2 \sin Q_n} \quad (17)$$

and

$$\frac{p^V}{p_0} = \sum_{n=1}^{\infty} A_n^V \exp(-DQ_n^2 t/l^2) \quad (18)$$

where

$$A_n^V = \frac{2H^2}{(H + H^2 + Q_n^2) Q_n^2} = \frac{2 \sin^2 Q_n}{(Q_n + \cos Q_n \sin Q_n) Q_n} \quad (19)$$

For large t the first term dominates giving as before simple exponential decay. Since from equation (5), $Q_1^2 \ll H$, then in general $A_1^V > A_1^I$ and will be close to unity.

If one, in addition looks at the situation for small H in this case, one gets as previously $\tan Q_1 \approx Q_1$, $Q_1^2 \approx H$.

Now if one substitutes this in equation (18) one gets the approximate relation that

$$\frac{p^V}{p_0} = \exp(-DHt/l^2)$$

But $H = KAl/V$; this leads to

$$\frac{p^V}{p_0} = \exp(-DKAt/lV) \quad \text{But } KD \text{ is the permeability } \underline{P}.$$

$$\frac{p^V}{p_0} = \exp(-\underline{P} At / l.V) \quad \text{This is essentially equation 8}$$

on page 21 in the previously reported theory ,in units of $\frac{\text{cm}^3 \cdot \text{cm}}{\text{cm}^2 \cdot \text{sec} \cdot 1 \text{ atmosphere}}$, which only holds for long time, thin wall,

and large void. The general theory thus reduces to the simplified situation previously given. This may, however, not be used for the general case, especially when calculations are to be made of the length of time of diffusion and permeation through a thick wall.

One must use the more general equations presented in this report, for thick wall calculations. These require a separate knowledge of solubility S (or C) and diffusion constant D , rather than their product P . The diffusion constant D is usually measured on thin-walled specimens by the TIME-LAG method as explained herewith:

In the early stages of the experiments, the decay of the function $f^x(p)$ is not a simple exponential, and terms with $n \geq 2$ contribute to the summation in equation(13). A time-lag, θ^x , may be defined as the time necessary to establish simple exponential decay with only one term in the series, of importance. Equation (14) may then be rewritten as

$$\ln [f^x(p)] = \frac{-DQ_1^2}{l^2} (t - \theta^x) \quad (20)$$

where the time-lag is

$$\theta^x = \frac{l^2}{D Q_1^2} \ln \frac{A^x}{Q_1^2} \quad (21)$$

For cases I and III ,as Q_1 approaches zero

$$\lim \theta^x = - \frac{l^2}{3 D} \quad (23)$$

For cases II and IV, as Q_1 approaches zero

$$\lim \theta^x = \frac{l^2}{6 D} \quad (25)$$

The dependence of $(\ln A_1^x)/Q_1^2$ is not very strong,¹³ and the limiting expressions may be used, giving an error of less than 1% for $Q_1 = 0.2$.

Once D has been measured by time-lag, and P from the steady state flow, then the solubility S is determined as P / D .

b) A Sample Calculation: how much time is required for pressure in a void to drop from atmospheric to 1 micron, and from atmospheric to 17 torr, due to diffusion outward into the vacuum of Space, thru a thick wall of Dow Corning 96-220.

At the time when the calculation was requested only Permeation data was available from previous measurements on Sylgard 185 and 184. No information was available on diffusion constant D or solubility S.

Step 1: Attempts to arrive at a reasonable guess of D and S.

(1) Telephone conversation June 25, 1976 with Dow-Corning's Dave Croffas.

Permeation data P for Sylgard types of silicone rubbers at 75°F

GAS	<u>P</u> in $\frac{\text{cm}^3 \cdot \text{cm}}{\text{cm}^2 \cdot \text{sec} \cdot \text{cm Hg}}$
N ₂	31 x 10 ⁻⁹
O ₂	61 x 10 ⁻⁹
CO ₂	243 x 10 ⁻⁹
H ₂ O vapor	1 x 10 ⁻⁵ $\frac{\text{gm} \cdot \text{cm}}{\text{cm}^2 \cdot \text{hour} \cdot \text{atm}}$
H ₂ O vapor	3 x 10 ⁻³ $\frac{\text{gm} \cdot \text{cm}}{\text{m}^2 \cdot 24 \text{ hour} \cdot \text{mmHg}}$

My own data for Sylgard 185

Air	43 x 10 ⁻⁹ $\frac{\text{cm}^3 \cdot \text{cm}}{\text{cm}^2 \cdot \text{sec} \cdot \text{cm Hg}}$
-----	-------------------------------------------------------------------------------------------------------------

(2) Telephone conversation June 29, 1976 with GE-Waterford-NY with Warren Lampe (518-237-3300).

Filled RTV 566 Silicone rubber D for O₂, N₂ = 15 x 10⁻⁶ cm²/sec.

The specific gravity of this compound = 1.5

The specific gravity of the pure polymer = 1.0

The specific gravity of the filler system = 4.2

This RTV is filled to 20% by weight.

So approximately it is filled 5% by volume.

(3) T. Crank and G. S. Park in Diffusion in Polymers by Academic Press, 1975, p 50, gives for Silicone rubber, filled

$$D \text{ for } O_2 \text{ at } 25^\circ C = 17 \times 10^{-6} \text{ cm}^2/\text{sec}$$

$$D \text{ for } N_2 \text{ at } 25^\circ C = 13 \times 10^{-6} \text{ cm}^2/\text{sec}$$

$$\text{Filler by weight} = 10\%$$

$$\text{Specific gravity of filler} = 2.2$$

$$\text{Specific gravity of polymer} = 1.0$$

$$\text{Filler by volume therefore is approximately} = 4\%$$

(4) Therefore it was decided from items (2) and (3) to use for the diffusion constant in this calculation thru Dow Corning's 96-220 :

$$D = 15 \times 10^{-6} \text{ cm}^2/\text{sec}$$

$$P = 43 \times 76 \times 10^{-9} \text{ cm}^2/\text{sec.atm} = 3.3 \times 10^{-6} \text{ cm}^2/\text{sec.atm}$$

$$S = \frac{P}{D} = 0.22 \frac{\text{cm}^3(\text{STP})}{\text{cm}^3.\text{atm}}$$

Step 2:

(1) As discussed in the Theory section, the first task is to calculate H.

$$H = KA1/V = KA1/Ah \quad (\text{See Fig. 40})$$

where $K = \text{STP}_s / T_s$. Here p_s and T_s are standard pressure and temperature.

To the degree of accuracy of this calculation $T = T_s$ at $25^\circ C$.

$$\text{Hence } K = 0.22$$

$$l = 1.3'' \text{ or wall thickness}$$

$$H = 0.22 \times \frac{1.3}{0.010} = 29.$$

$$h = 0.010'' \text{ or void depth}$$

See Fig. 40

This is a very, very large H. In other words, the supply of dissolved air in the wall of potting compound is much greater than in the thin sliver of delamination gap.

(2) Solve for the Q 's from

$$Q_n \tan Q_n = H$$

to get the non-zero, positive roots. This is the set of first quadrant, third quadrant solutions. These are easiest obtained from a graph or from a Table ^H as given here:

TABLE IV¹⁴

To Aid in Obtaining Solutions for $Q_n \tan Q_n = H$

1st quadr.	3rd quadr.			
Q_1	$Q_2 = Q_1 + \pi$	$\tan Q$	$Q_1 \tan Q_1$	$Q_2 \tan Q_2$
.1	3.24	.1	.01	
.2	3.34	.2	.04	
.3	3.44	.31	.093	
.4	3.54	.42	.168	
.5	3.64	.54	.27	
.6	3.74	.69	.41	
.7	3.84	.84	.59	
.8	3.94	1.03	.82	
.9	4.04	1.26	1.13	
1.0	4.14	1.56	1.56	
1.1	4.24	1.96	2.16	
1.2	4.34	2.58	3.1	
1.3	4.44	3.6	4.68	
1.4	4.54	5.9	8.26	26.8
1.45	4.59	8.34	12.1	38.3
1.5	4.64	14.3	21.4	66.3
1.55	4.69	49.1	76.1	
1.56	4.70	85.9	134.	
1.568	4.708	344.	539.	
1.57	4.71	∞	∞	

Since in this case $H = 29$, the interpolation gives $Q_1 = 1.51$ and $Q_2 = 4.54$. Higher Q 's give terms that are negligible for any appreciable length of time because of the negative exponential character of the series solution for the pressure in the void, and are not needed therefore.

(3) One has the case here where the wall is saturated at atmospheric pressure to begin with. Then the pressure is reduced to zero at the outer surface due to exposure to the vacuum of Space. According to the Theory section this is an example of case II.

$$\frac{p^{II}}{p_o} = \sum_{n=1}^{\infty} A_n^{II} \exp(-DQ_n^2 t/l^2) \quad (9)$$

$$\text{where } A_n^{II} = \frac{2(H^2 + Q_n^2) \sin Q_n}{(H + H^2 + Q_n^2) Q_n} \quad (10)$$

For large t , because of the exponential nature of equation (9), the Q_1 dominates. For large H , as here, the simplified

$$A_n^{II} = 2 \times \frac{843}{874} \times \frac{\sin Q_n}{Q_n}$$

$$\text{So } A_1^{II} = 2 \times \frac{843}{874} \times \frac{1}{1.52} = 1.28$$

$$A_2^{II} = 2 \times \frac{(-1)}{4.54} = -0.44$$

Therefore, using only the first term of the series in equation (9) one gets

$$2.3 \log \left(\frac{p^{II}}{p_o} \right) = 2.3 \log A_1 - DQ_1^2 t/l^2 \quad (20)$$

$$2.3 \log \frac{10^{-3} \text{ torr}}{760 \text{ torr}} = 2.3 \log 1.28 - \frac{15 \times 10^{-6} \times (1.52)^2 t}{(3.3)^2}$$

This gives

$$t = 4.3 \times 10^6 \text{ seconds} = 50 \text{ days} + 2 \text{ days time lag.}$$

Since the Silicone rubber in the Dow Corning 69-220 is heavily filled, to about 24% of the volume, then the diffusion constant might be expected to be lower by the same percentage, hence the length of time would be 24 % longer or about 63 days altogether, *+ 2 days time lag.*

The Paschen curve calibration of the vidicon tube base, to be discussed later, showed that with 900 volts on adjacent naked metal pins, breakdown would first be expected at 17 torr of pressure. So one can ask how long for breakdown to occur if p^{II} is to be 17 torr down from p_0 of 760 torr at the start. This makes the left-hand term in equation (20) equal to $2.3 \log \frac{17}{760} = -3.8$. This would yield

$$t = 1.3 \times 10^6 \text{ seconds} = 15 \text{ days} + 2 \text{ days time lag,}$$

or for 24% filled material by volume would give 19 days.

*+ 2 days
time lag.*

c) Measurement of Diffusion Coefficients on Silicone Rubbers.

As mentioned earlier, it is necessary to measure the diffusion constant D , in addition to the permeation constant P . This is easiest carried out by the Time-Lag approach, discussed in the Theory section. One chooses to do the experimental work on thin-walled, large-void samples, so that the salient Material Constants can be extracted from the data by the simplest approximation to the exact solution of the Diffusion equation. To this end, cylinders of the various silicone rubbers were cast with thin wall, large void, using the same mold as in the previous report. This time a Veeco DV4M thermocouple tube was sealed in the top of each unit rather than a high voltage spark gap. Internal pressures could be smoothly followed with this tube to about 15 torr. See Figure 34.

The cylinder in question was evacuated inside, the glass tube sealed off, and then it was immediately placed in a vacuum system at 10^{-3} torr and left there between 3 to 4 weeks. During this time it was hoped that the thin walls would be essentially emptied of dissolved air. The unit was then removed from the vacuum system and the thermocouple tube plugged in as rapidly as possible (Time to do this operation was about $\frac{1}{2}$ minute). Indeed, a definite time-lag was observed. The pressure gage remained absolutely constant, almost as though inoperative, for about 10 minutes for these silicone rubber cylinders, before indicating an increase of pressure as air finally reached the inside wall and permeated through.

Graphs were plotted of cavity pressure versus time, as shown in Figures 36 to 39. This is plotted on linear paper rather than semilog because it has been suggested that after 2.5-3 times the time-lag, that

Fig. 34

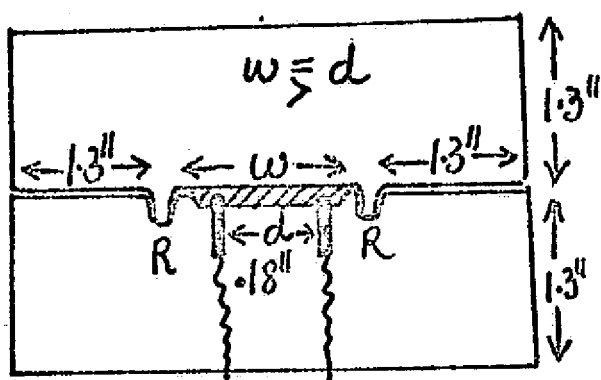
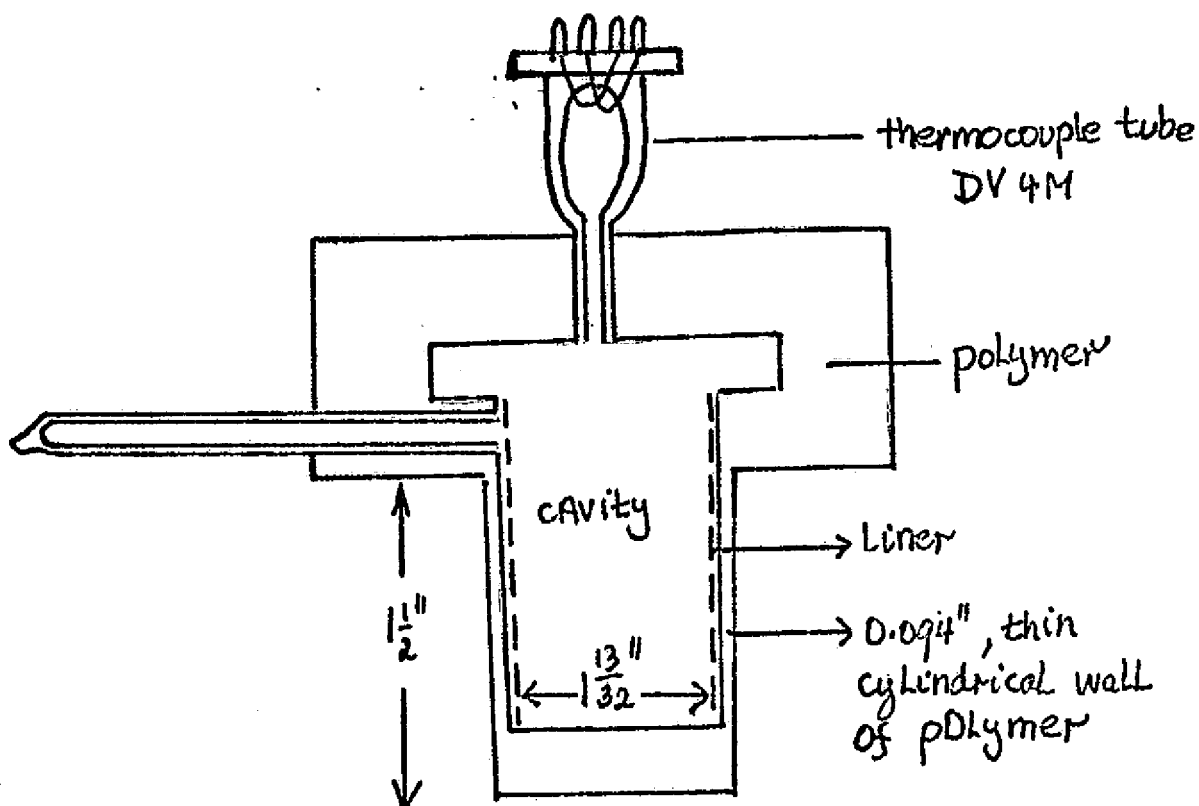


Fig. 35 a)

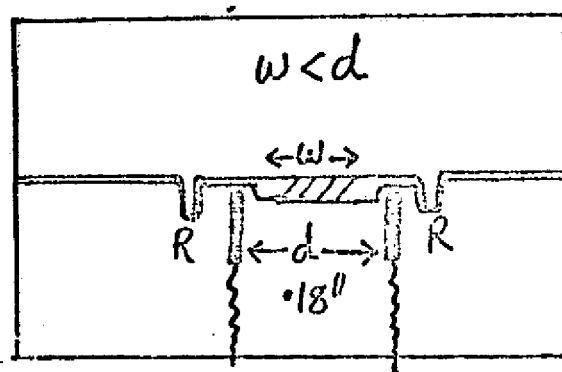


Fig. 35 b)

steady state flow conditions are achieved to a good approximation

for thin walls. In fact, the time region of approximate steady flow extends between $t = l^2/2D$ and $t = 3 \frac{l^2}{40 H D}$

according to an article by Jenkins, Nelson and Spirer. Thus, the time-lag is obtained from the intersection of the horizontal constant pressure line with the rising linear portion of the graph of pressure versus time.

The diffusion constant is then calculated from $\theta^x = l^2/6D$.

The permeation constant is calculated from the rising linear portion by the following further approximation:

From equation (20) $f^x(p) = e^{-DQ_1^2(t-\theta)/l^2}$

The experimental procedure fits with case IV of the Theory.

Hence

$$f^x(p) = 1 - p_x/p_c$$

Thus

$$1 - p_x/p_c = e^{-DQ_1^2(t-\theta)/l^2}$$

For large t (but short enough for the p_x in the cavity to still remain negligible compared to the outside pressure) the exponential term can be approximated by the first two terms in its series expansion

$$\text{Thus } 1 - p_x/p_c = 1 - \frac{DQ_1^2(t-\theta)}{l^2} + \dots$$

Therefore

$$p_x/p_c \approx \frac{DQ_1^2(t-\theta)}{l^2}$$

For small H (thin wall, large void) , $Q_1^2 = H$ and $H = \frac{STp_s Al}{T_s V}$

Hence

$$p_x/p_c = \frac{DSTp_s Al(t-\theta)}{T_s V l^2}$$

But

$$D.S = \underline{P}$$

Fig. 36.

DOW CORNING:

SYLGARD 184

Pin cavity,
torr

$$V_0 = 28.5 \text{ cm}^3$$

$$A = 18 \text{ cm}^2$$

$$L = 0.24 \text{ cm}$$

$$V_{\text{GAGE}} = 8.5 \text{ cm}^3$$

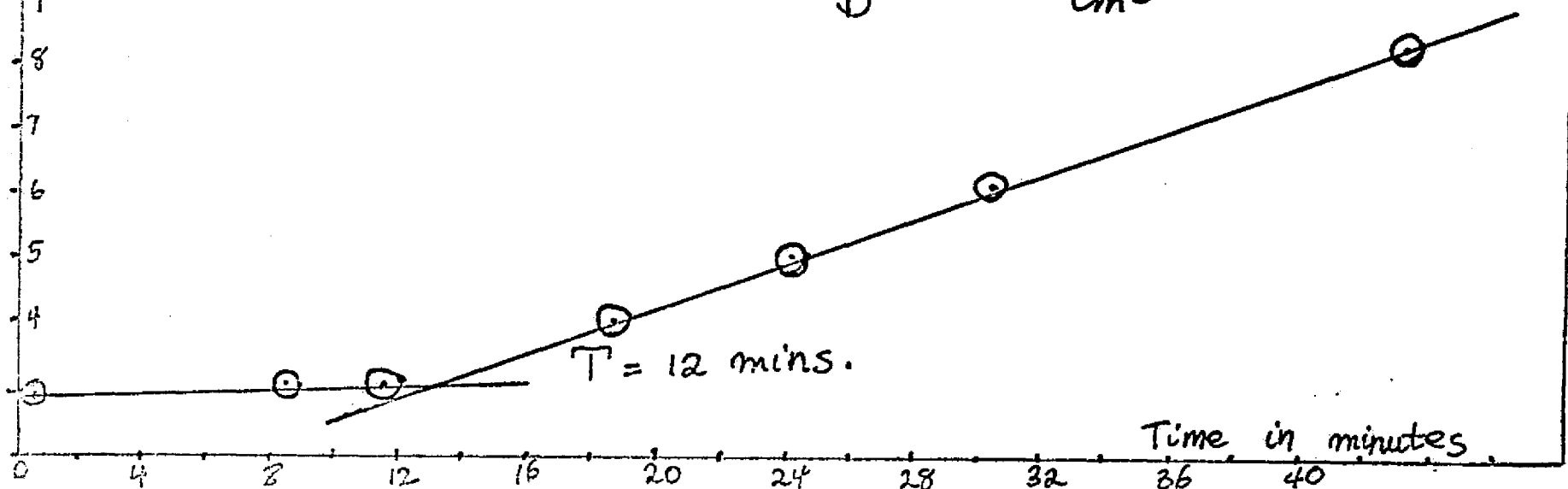
$$V_{\text{TOTAL}} = 37 \text{ cm}^3$$

$$D = 13.1 \times 10^{-6} \text{ cm}^2/\text{sec}$$

$$P = 26 \times 10^{-9} \times 76 \frac{\text{cm}^2/\text{sec}}{\text{atm}}$$

$$= 20 \times 10^{-7} \frac{\text{cm}^2/\text{sec}}{\text{atm}}$$

$$S = \frac{P}{D} = 0.16 \frac{\text{cm}^3}{\text{cm}^3/\text{atm}}$$



P in cavity,
torr

DOW CORNING
Sylgard 184

Fig. 37

$$D = 14 \times 10^{-6} \text{ cm}^2/\text{sec}$$

$$P = 36 \times 10^{-9} \times 76 \frac{\text{cm}^2/\text{sec}}{\text{atm}}$$

$$= 27 \times 10^{-7} \frac{\text{cm}^2/\text{sec}}{\text{atm}}$$

$$S = \frac{P}{D} = 0.19 \frac{\text{cm}^3}{\text{cm}^2/\text{atm}}$$

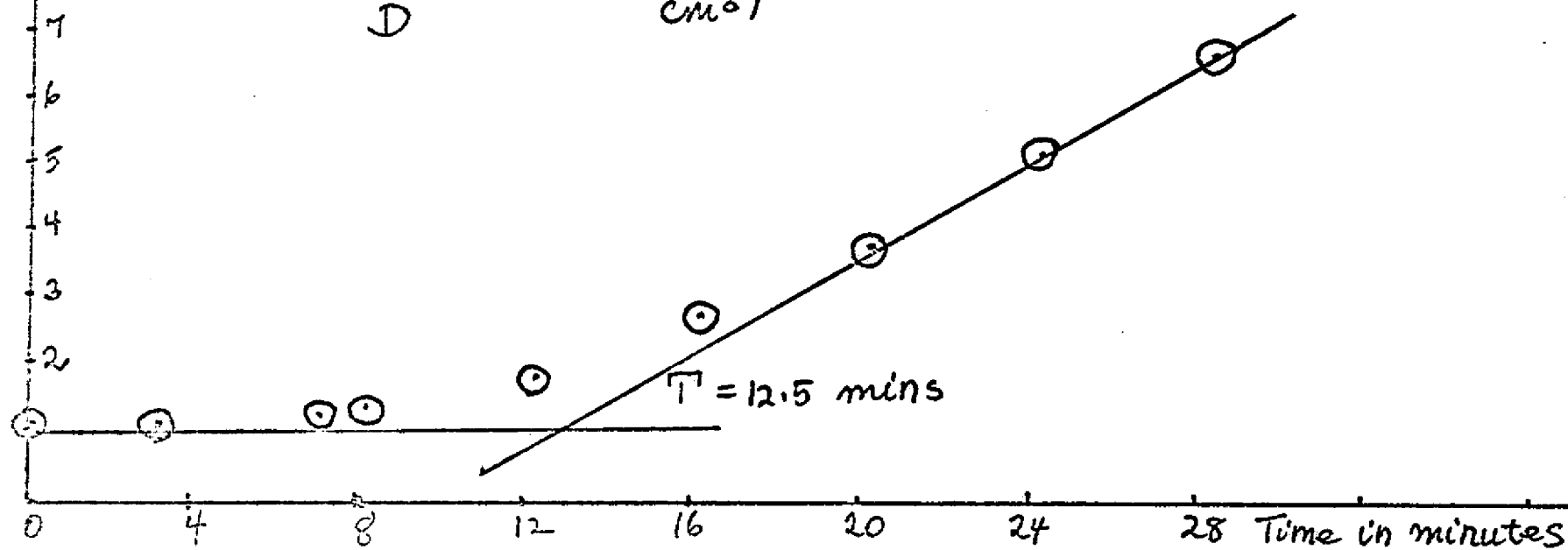


Fig 38

DOW CORNING 93-500

P in cavity,
torr

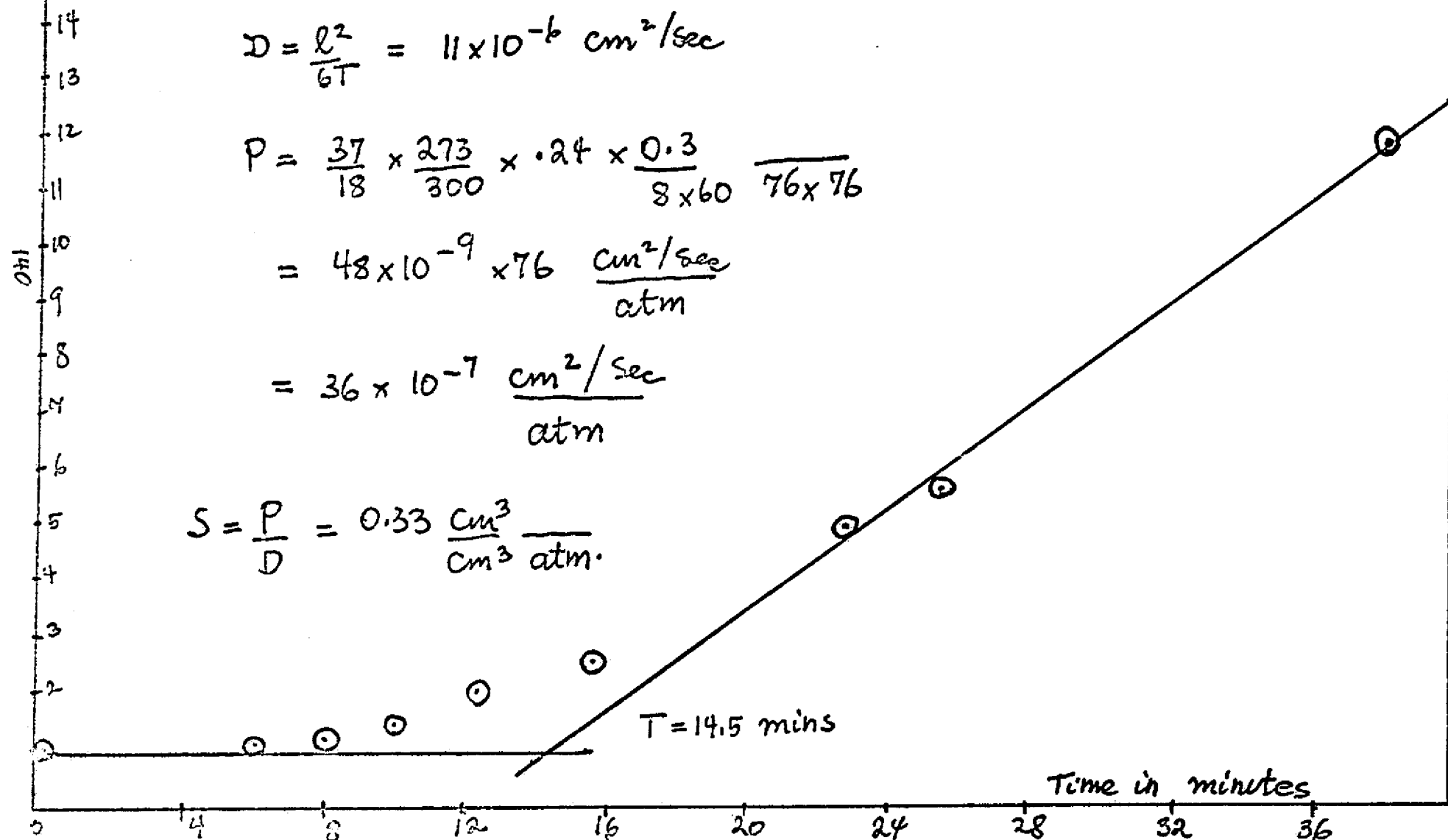
$$D = \frac{l^2}{6T} = 11 \times 10^{-6} \text{ cm}^2/\text{sec}$$

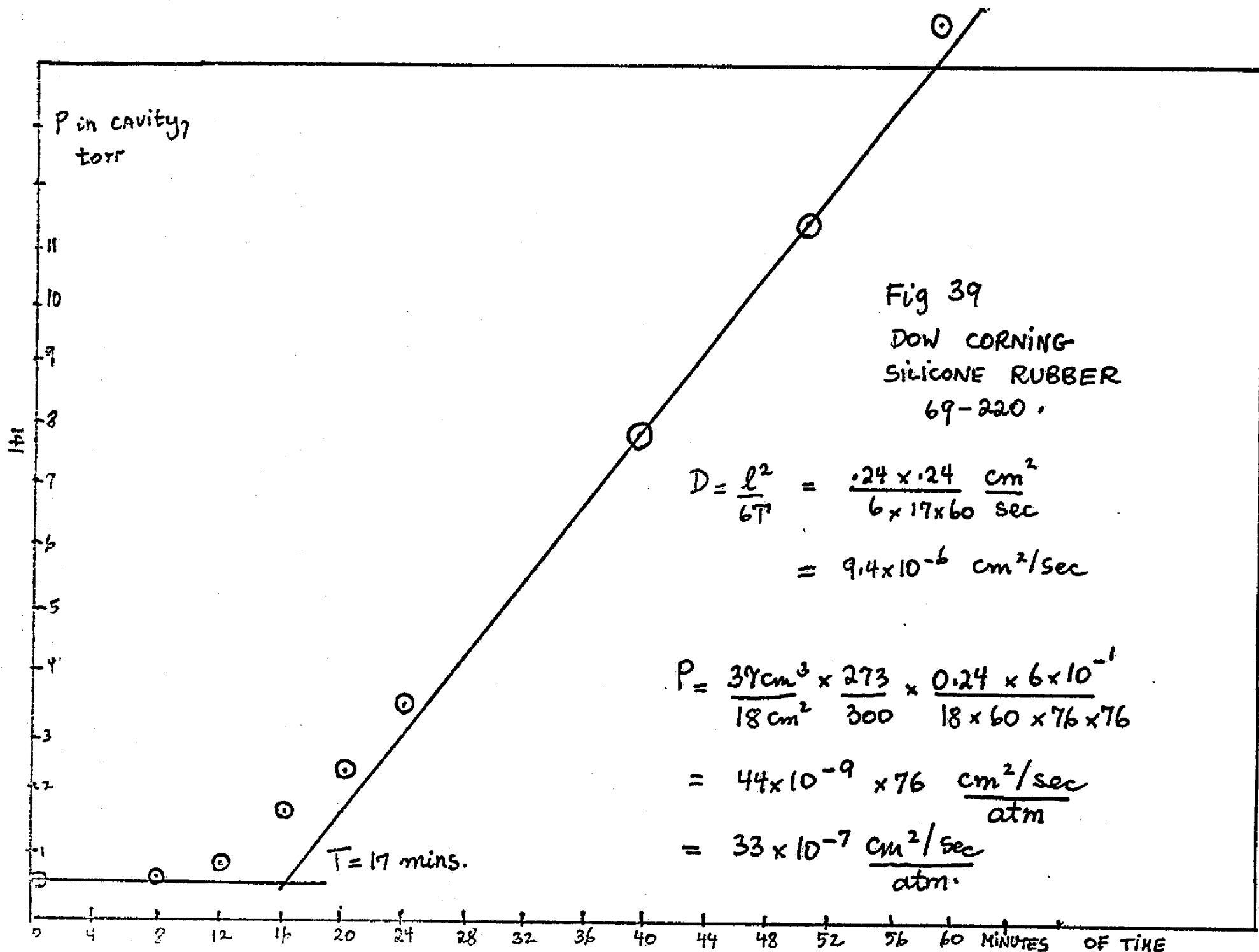
$$P = \frac{37}{18} \times \frac{273}{300} \times 0.24 \times \frac{0.3}{8 \times 60} \times \frac{76 \times 76}{76 \times 76}$$

$$= 48 \times 10^{-9} \times 76 \frac{\text{cm}^2/\text{sec}}{\text{atm}}$$

$$= 36 \times 10^{-7} \frac{\text{cm}^2/\text{sec}}{\text{atm}}$$

$$S = \frac{P}{D} = 0.33 \frac{\text{cm}^3}{\text{cm}^3 \text{ atm}}$$





Therefore

$$P = \frac{V.l.T_s \cdot p_x}{A.T.p_s.p_c(t-\theta)}$$

But p_s and p_c are each 76 cm Hg or atmospheric pressure, and instead of $p_x/(t - \theta)$ one can use the slope of the linearly rising graph $\Delta p/\Delta t$

Therefore $P = \frac{V.l.\Delta p.273}{A \Delta t.300 \cdot p_c \times 76 \text{ cm Hg}}$

This is equation (6) of the previous report and is used again to calculate permeation constants here. Table V gives a summary of results.

Table V

Difussion of air through silicone rubbers. Measurement results at 27°C

Name of silicone rubber (Dow Corning)	Measured P in $\frac{\text{cm}^3.\text{cm}}{\text{cm}^2.\text{sec}.\text{cm Hg}}$	P in $\frac{\text{cm}^2}{\text{sec}.\text{atm}}$	D $\frac{\text{cm}^2}{\text{sec}}$	S $\frac{\text{cm}^3}{\text{cm}^3.\text{atm}}$
Sylgard 185(in 1974)	43×10^{-9}			
Sylgard 184(in 1974)	30×10^{-9}			
Sylgard 184(in 1976)	26×10^{-9}	20×10^{-7}	13×10^{-6}	0.16
	36×10^{-9}	27×10^{-7}	14×10^{-6}	0.19
93-500 (1976)	48×10^{-9}	36×10^{-7}	11×10^{-6}	0.33
69-220 (1976)	44×10^{-9}	33×10^{-7}	9.5×10^{-6}	0.35
Information from other sources				
From Dow Corning				
Sylgard "types", 75°C	$31 \times 10^{-9}, N_2$ $61 \times 10^{-9}, O_2$			
From Ge, Waterford RTV 566			15×10^{-6} for O_2, N_2	
From Crank & Park, Diffusion in Polymers Silicone Rubber, Dow Corning			$13 \times 10^{-6}, N_2$ $17 \times 10^{-6}, O_2$	

One can now recalculate the time for pressure to get down to 17 torr from atmospheric pressure as done in part b) earlier. One can now use the measured Material Constants for the Dow Corning 69-220 rather than the assumed constants. The solubility being 0.35 instead 0.22 does not influence the results because of the insensitivity of the diffusion equation solution to variations in H for very large H. The fact that the D is 9.5×10^{-6} instead of 15×10^{-6} does cause a changed result, namely time t

$$t = 2.0 \times 10^6 \text{ seconds} = 24 \text{ days.}$$

One should also check by numerical calculation that the higher terms in the series solution are indeed negligible for long times t. To this end, one can compute the first and second terms in

$$\frac{p}{p_0} = \sum_n A_n \exp(-DQ_n^2 t/l^2)$$

Assume t as already found, namely $t = 2 \times 10^6$ seconds

Term #1:

$$Q_1 = 1.52$$

$$A_1 = \frac{2}{1.52} = 1.28$$

$$A_1 \exp() = 1.28 \exp\left(\frac{-9.5 \times 10^{-6} \times 2.25 \times 2 \times 10^6}{3.3^2}\right) \\ = 1.28 \exp(-4.5)$$

Term #2:

$$Q_2 = 4.54$$

$$A_2 = \frac{-2}{4.54} = -0.44$$

$$A_2 \exp() = -0.44 \exp\left(\frac{-9.5 \times 10^{-6} \times 20 \times 2 \times 10^6}{3.3^2}\right) \\ = -0.44 \exp(-40)$$

This is certainly negligible compared to the first term #1.

The insensitivity of the diffusion equation solution to variations in H for very large H is somewhat disturbing from the physical point of view, and is being looked into further.

d.) Insulation Problem on Landsat-C vidicon tube.

The problem is best illustrated by Figure 40. The 16-pin vidicon tube base is seen to be potted in Dow Corning silicone rubber 69-220, to a thickness of 1.3 inches. There was delamination across the glass bottom of the vidicon tube. The X-rays showing this delamination varied somewhat from tube to tube. Also, the void became thicker when the temperature was warm (about 50°C), and it disappeared when the tube was exposed to the cold (about -30°C). The X-rays were not clear enough to show whether the thin delamination followed all the way up each small glass mound surrounding each metal pin at the tube base, or whether it was restricted to the flat portion of the tube base.

The approach to the problem was multifaceted as outlined in Table VI. According to items A.), B.), C.) in this Table the actual flight-quality tubes had their pottings vented with a suitable nylon drill by GSFC personnel and RCA. As concerns the author of this report the following was investigated according to items D.) and E.) in this Table.

First, Paschen curves of pressure versus breakdown voltage were obtained on a vidicon tube base, one with voltage applied between neighboring pins, 0.185" apart, and then between diametrically opposite pins, 0.97" apart. A 900 volt horizontal line intersects the former curve at 17 torr and a 2700 volt line intersects at 37 torr. Since these voltages are actual flight voltages applied to these pins, then the corresponding pressures are those at which breakdown should first be observed as air diffuses out of the void. How to calculate the time length for this to happen has already been shown earlier.

TABLE VI :

LANDSAT MEETING, 11 a.m. July 16, 1976, Lou Wilson's Office
GSFC, Code 430.

- A.) Establish size, geometry, number and vent location (RCA concurrence required) for each of tubes 30, 31, 17.
- B.) Qualify (Test Housings) vent manufacturing procedure (RCA concurrence required).
- C.) Qualify (Test Housings) for design modifications A.) and B.), including outgassing measurement*; by either electrical discharge or breakdown measurement.* Outgassing versus vacuum pump time measurement. w o v v
- D.) XD 5246 (Experimental Vidicon Tube) w v v

Diffusion and Partial Discharge. Also S 19923. (Note: Since X-rays have already shown that the void extends all the way across the base of the XD 5246, then this will also have to be measured by total breakdown, rather than partial discharge. Partial discharge is suitable for voids and cracks in potting when these extend PARTIALLY, PART OF THE WAY between the electrodes. ALL THE WAY discharges from electrode to electrode is damaging to the FET input preamplifier, on the partial discharge equipment.)

- E.) Simulation void (catastrophic breakdown) study on two GSFC manufactured housings (samples).
- F.) Electric Field measurement on RCA experimental Vidicon gun sample.
- G.) Potting improvement in experimental S 19923 and potting sleeve 1978793-1.
- H.) Review with RCA/Camden their latest potting effort.

Copied from the blackboard by Renate S. Bever.

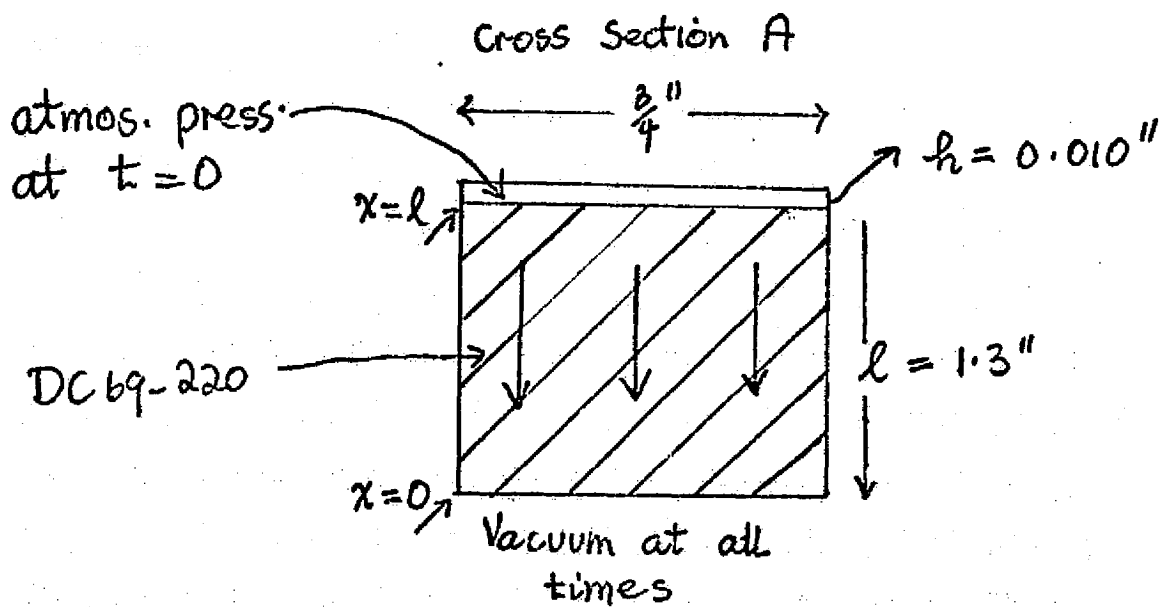
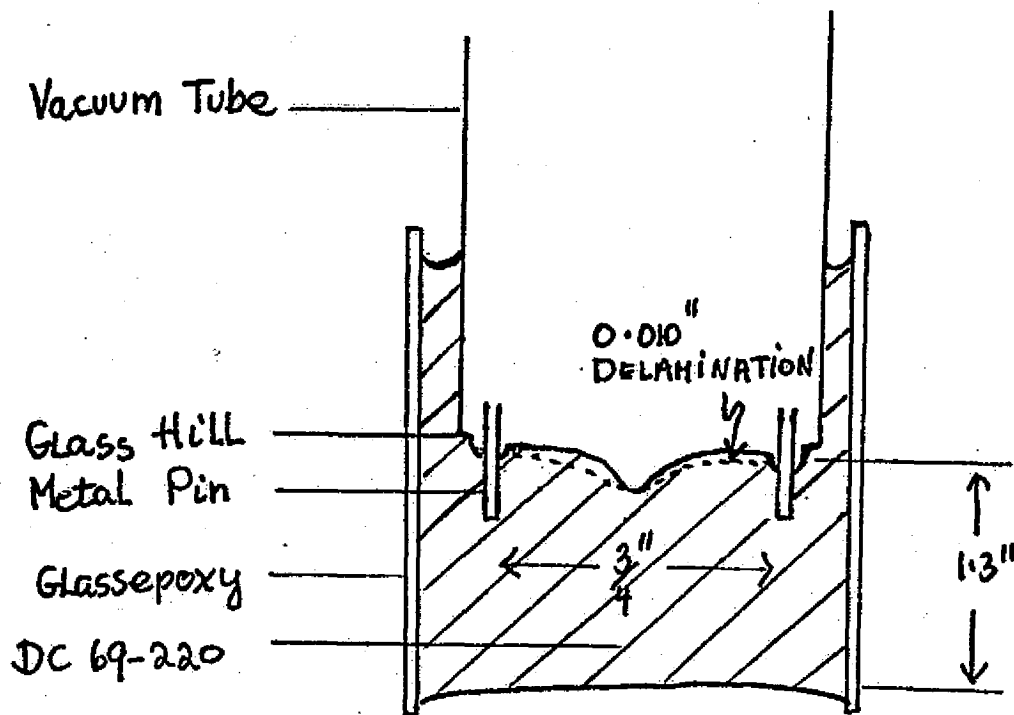
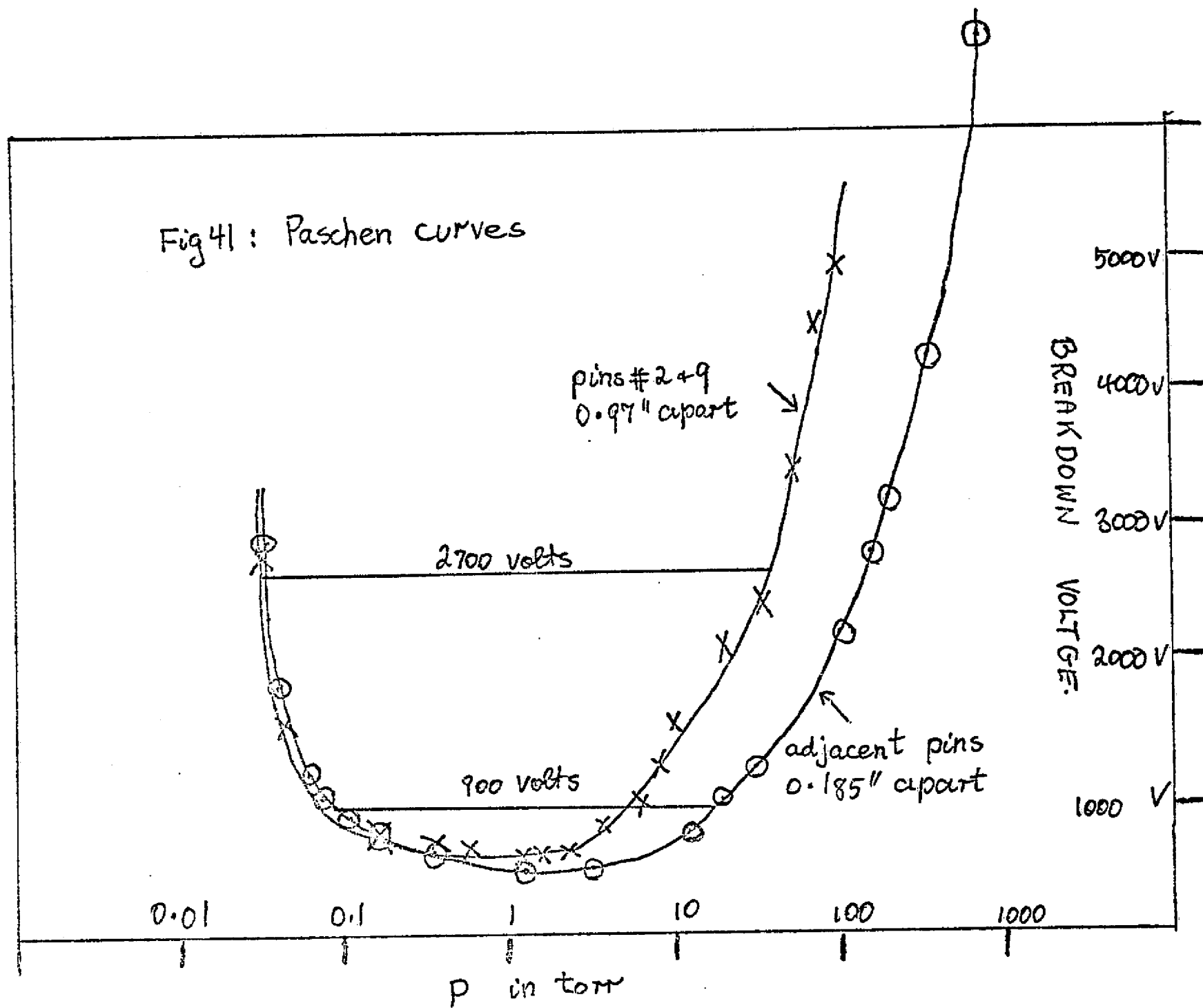


Fig. 40.

Fig 41: Paschen curves



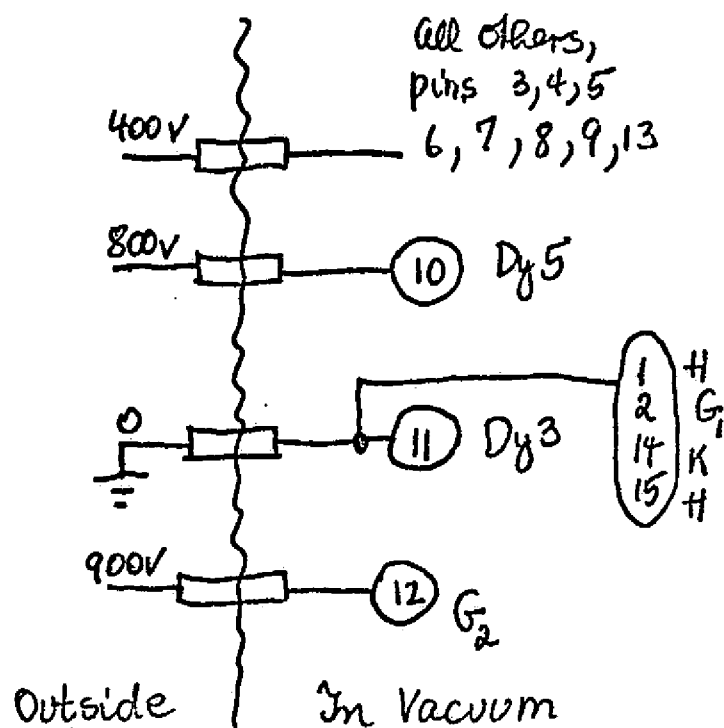
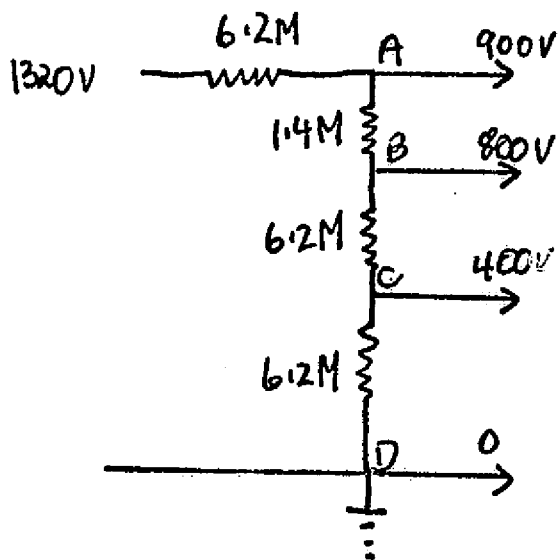
Second: An actual Landsat-C vidicon tube, #XD 5246, without vent, was mounted in a Vac-Ion vacuum chamber at pressures lower than 10^{-7} torr, and high voltage was continuously applied. A microammeter sensitive to one microampere was included in the ground line of the circuit to monitor for evidence of catastrophic breakdown. This was carried on for many weeks and no evidence of catastrophic breakdown was ever observed. The three sequences of the experiment were as follows:

a) Voltages were applied continuously so as to have 800 volts between pins 11 and 10 and 900 volts between pins 11 and 12. See Figure 42. This was left continuously applied with the tube in high vacuum for 93 days. b) Without breaking vacuum the connections to the tube were revised to closer simulate the actual connections in flight;- pin 10 was grounded, pin 11 was at 900 volts with respect to it and pin 12 was at 1700 volts with respect to it. This was maintained for 7 additional days. c) The tube was continued in vacuum with no voltages applied, for 3 more months. Then the voltages were reconnected.

As stated earlier no evidence of catastrophic breakdown was ever observed.

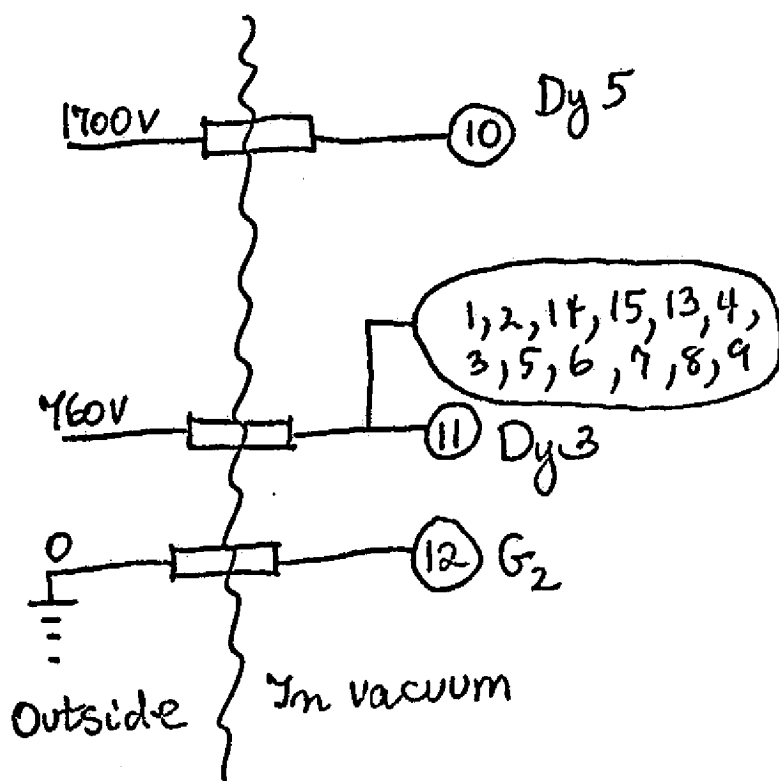
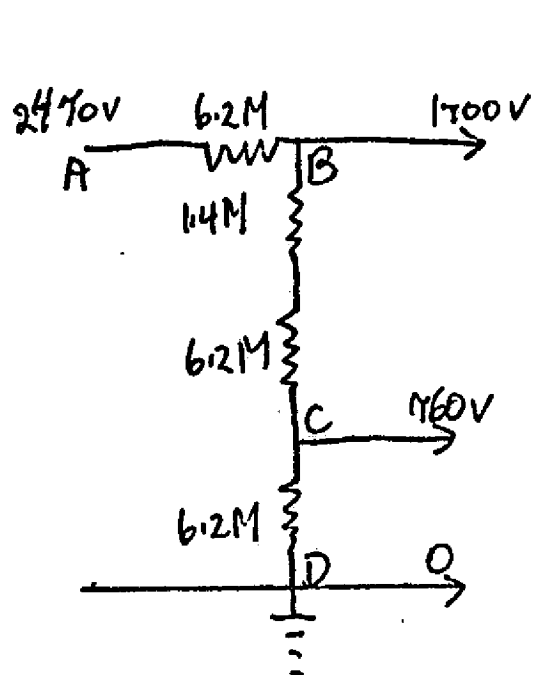
It would have been informative to have raised the voltages on the pins above the Flight-simulation values until breakdown occurred, but this was not approved by the project monitor of Landsat-C at the time.

Third, according to portion E.) of the test plan, four cylindrical lugs of potting material with simulated thin voids, were manufactured in a plastics shop, as illustrated in cross-section in Figures 35. One was made of Sylgard 184, naked pins exposed to the void, and three were made of DC 69-220. Two of these had naked pins exposed to the void; one had the pins coated with potting compound.



If	I_{Expected} μa	$I_{\text{Meas.}}$ μa
No short	65	68
Short, AD	213	
Short, BD	174	
Short CD	96	
Short AC	107	
Short BC	96	

Fig 42



If	I_{expected} μA	I_{meas} μA
No shorts	124	125
Short, BC	200	
Short, CD	179	

Fig. 43

These slugs were manufactured in three stages, namely two pouring and one cementing together:

- 1) Pour one half with about a 20 mil depression at bottom, electrodes spaced 4 cm apart (0.18") and well primed. The electrodes were actual nearest pins from the base of a vidicon tube and supplied by RCA.
- 2.) Pour the other half. Inspect the metal pins carefully to make sure that the metal pins are either naked where they protrude into the depression or coated completely where so intended.
- 3.) Cement the two halves together with more of the same potting compound, being sure that the cement does not squeeze into and fill up the void. The rill R is really a ring that has purposefully been cast into the two halves to make a longer "squeezing" path for excess cement. In case the area around the rill does not completely fill up, it does not matter- one then simply has a larger diameter void in a weak part of the electric field. The dimensions simulate the vidicon tube problem- that is, 1.3" diffusion path thru the encapsulant, and a 0.010" to 0.020" high void.

These samples were alternately placed in vacuum for a long time, tested for catastrophic breakdown, and then placed at atmospheric pressure for a long time and tested again- back and forth. Table VII summarizes the results of these measurements.

Table VII.

Breakdown Voltages after exposure to Vacuum and to Atmospheric Pressure

Unit #	Material	After exposure to	Breakdown Voltage
1	DC 69-220 Naked Pins	Vacuum, 22 days Nov. 2-Nov 24,76	2000 volts
2	DC 69-220 Naked Pins	" "	2000 volts
3	DC 69-220 Encapsulated Pins	" "	not tested
4	Sylgard 184	" "	not tested
1		More Vacuum, 58 days more Nov. 24,76-Jan 27,77	1300 Volts
2		" "	1500 volts
3		" "	tested up to 9000 volts, no breakdown
4			2500 volts
1		Atmospheric Press., 75 days, Jan 27- April 13	8500 volts
2			7000 volts
3			tested up to 10,000 v, no Breakdown
4			6500 volts
1		More Atmospheric, 33 days more Apr. 13-May16	7400 volts
2			6250 volts
3			tested up to 20,000 volts no Breakdown
4			6000 volts

Table VII continued.

1	Vacuum, 33 days May 17-June 20	1750 volts
2		2250 volts
3		tested up to 20,000 v no breakdown
4		3000 volts

Conclusions are

- a) There is definite evidence of diffusion into and out of the void, as the breakdown voltage is lowered markedly after vacuum exposure and raised again after atmospheric pressure and lowered again after repeated vacuum exposure. The lowering is not as much, however, as predicted by the theoretical calculations.
- b) There is no catastrophic breakdown in the unit #3 which has the pins coated with potting material rather than naked metal exposed to the void.

One can now speculate why there was no breakdown between the pins in the base of vidicon tube #XD 5246:

- 1) Perhaps the delamination did not extend or climb up the glass hills from which each metal pin protruded; in other words, naked metal was not exposed to the void. One should then not expect catastrophic breakdown. One should be able to detect partial discharge, and this will be one of the measurements in the near future.
- 2) The diffusion constant for Silicone rubber might not be a constant, but might be less for thick than for thin sections for which it was measured, and which was used in the calculations.
- 3) There might always be enough outgassing from the thick walls into the tiny cavity so as to maintain the pressure at values that call for higher applied voltages to cause breakdown than were felt to be safe to apply to the vidicon tube at the time of the testing and not damage its inner electrodes. If caution is allowed to be thrown to the winds, then it will be an easy task to check on this hypothesis.

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